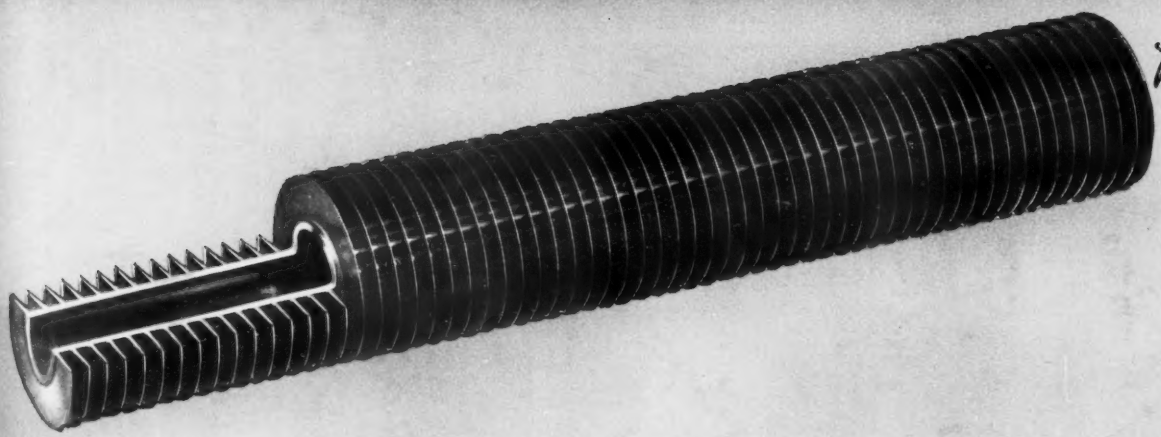
Nuclear Power

The journal of British nuclear engineering



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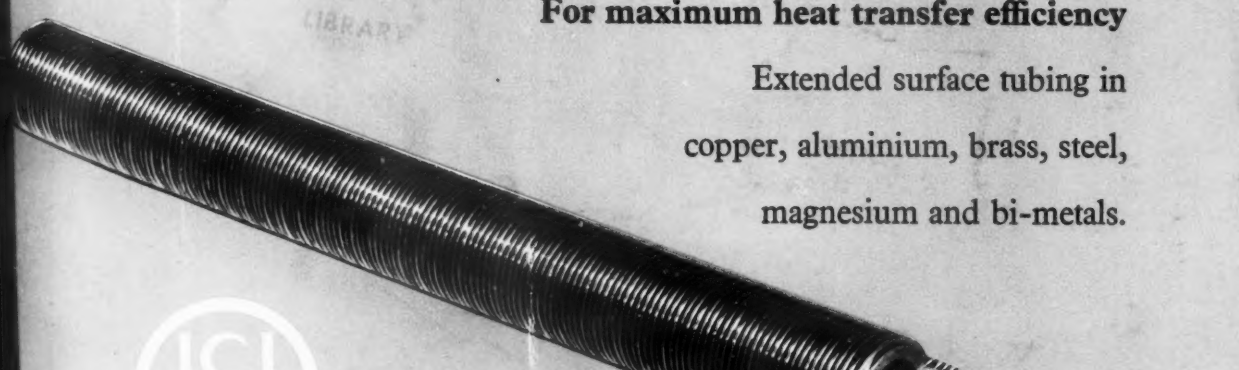

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METALS DIVISION

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September 1956 volume I number V 3s 6d

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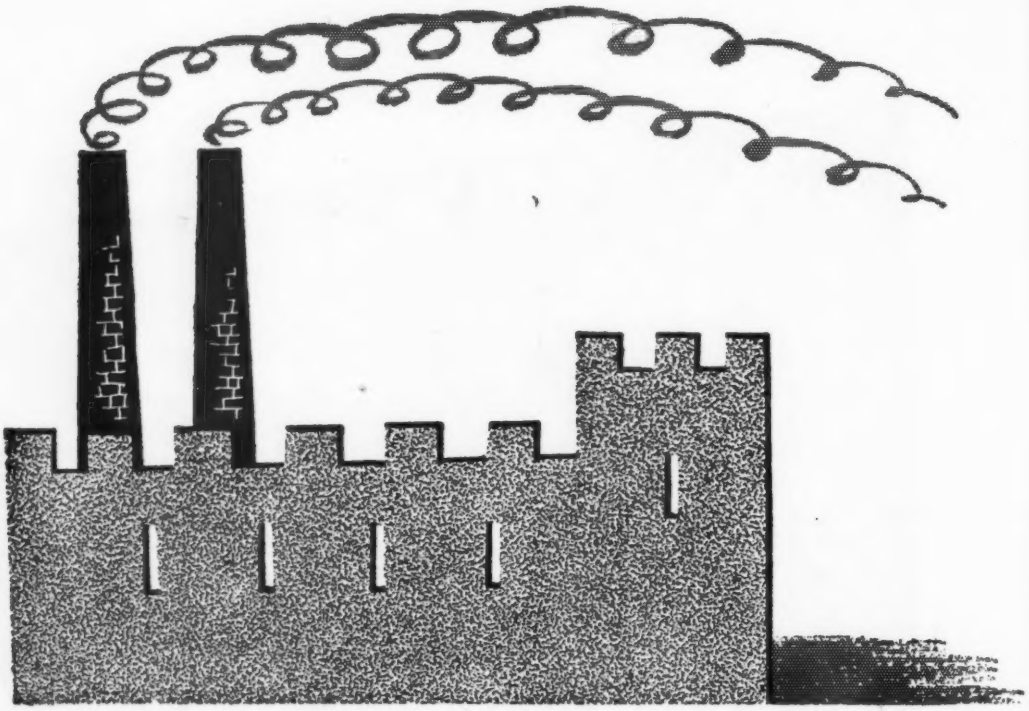

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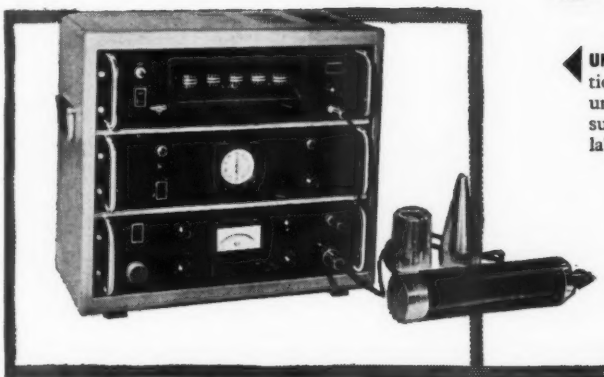

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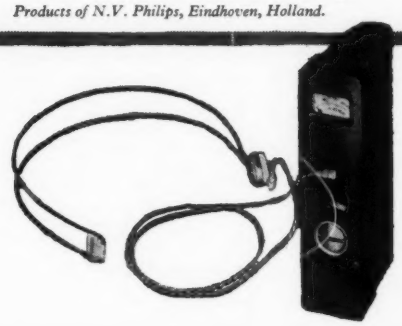

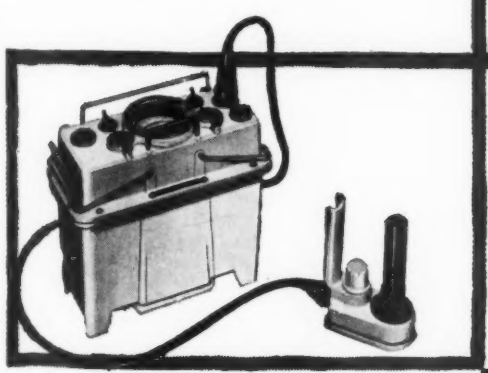

CONTAMINATION METER TYPE 1092D. Will accurately measure gamma activity on clothing benches, etc., in terms of milli-roentgens per hour at a specified distance. The 1092D is provided with alternative and readily interchangeable power supply units which may be (i) a high tension battery (ii) a mains unit, or (iii) a vibrator unit, according to choice. In the interests of maintenance, minimum size and weight, cold cathode valves are used throughout—thus obviating the need for filament heating.

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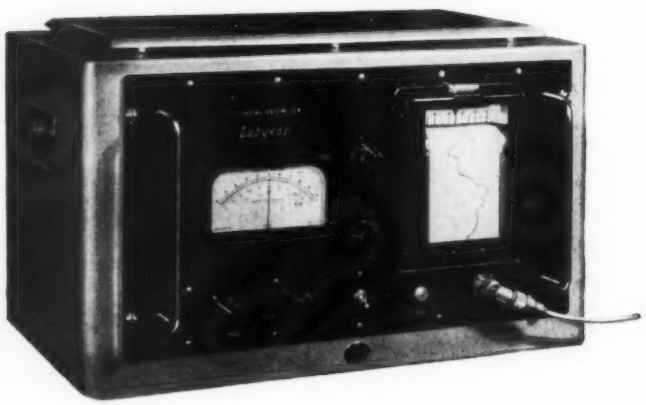

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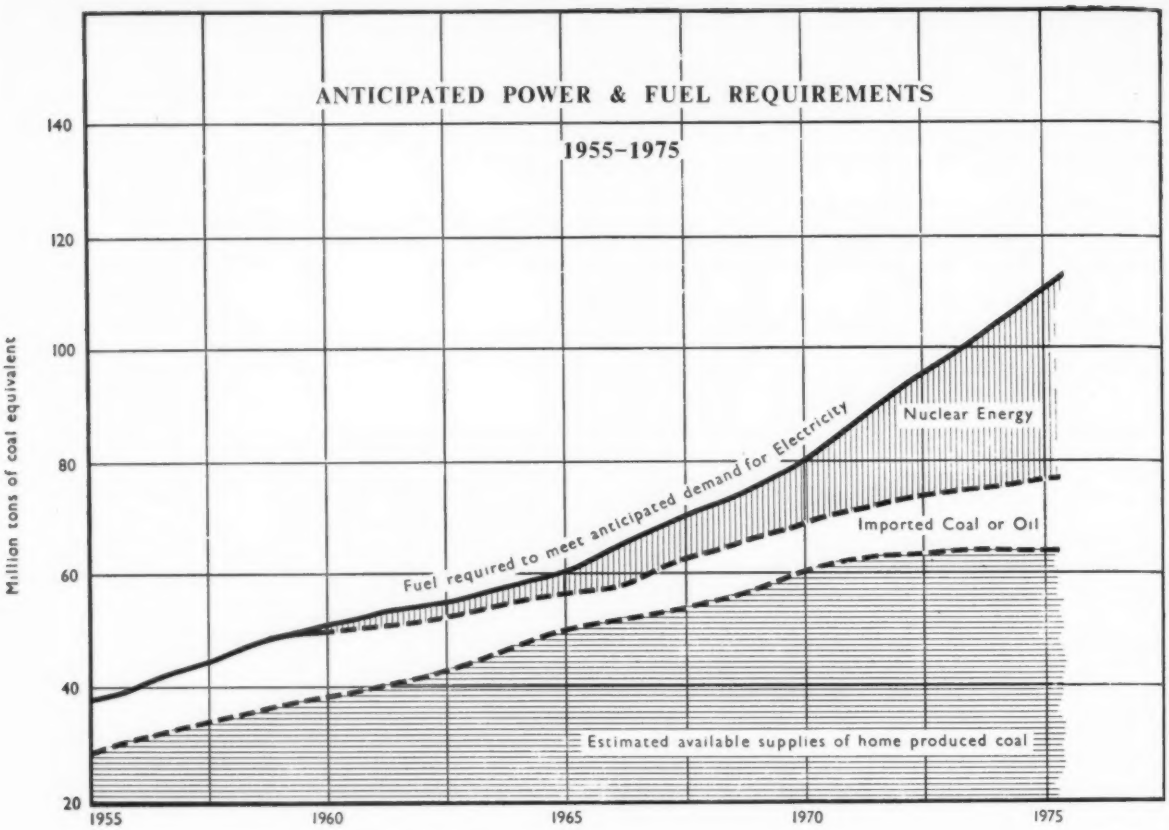

Electricity from Nuclear Energy

A 20-year development programme

Britain's nuclear power station construction programme will go far to offset the growing shortage of coal in the next two or three decades.

The First Ten Years

Work will start on the first two nuclear power stations in 1957. These will each have two gas-cooled reactors and the stations will be in operation by 1960/61. Two further gas-cooled reactor stations — each housing two reactors of improved type — to be begun in 1958/9 will come into service by 1963. The output of these four stations will be between 400,000 - 800,000 kilowatts.

The construction of two groups of four stations each will begin in 1960 and 1961/2 and they will be supplying electricity to the Grid by 1963/4 and 1965 respectively. The first group of stations will probably have one gas-cooled reactor each. The second will probably utilise liquid-cooled reactors — one high rated reactor each. These stations will add well over 1,000,000 kilowatts to the nation's power resources.

The Second Ten Years

By 1975, it is anticipated that nuclear reactor power stations in Britain will have an aggregate installed capacity of between 10,000,000 and 15,000,000 kilowatts. Since these stations will be operated as base load stations working at full output for twenty-four hours a day they will be responsible for possibly half the units generated in the country.

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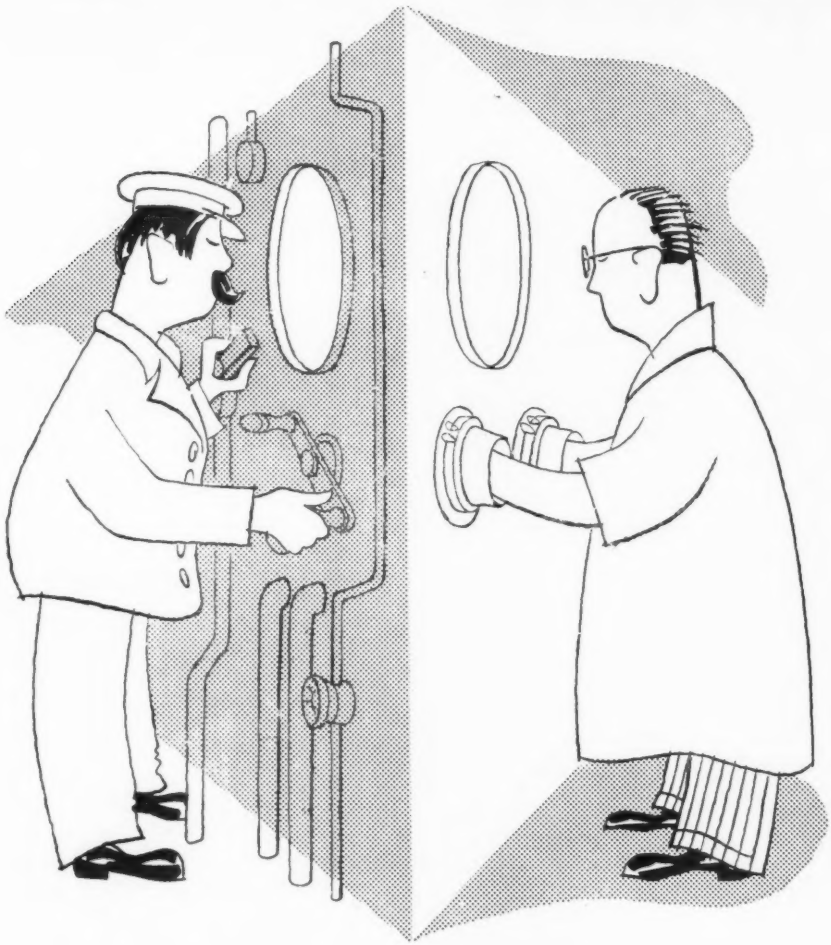
In ten years' time — 1,500,000 to 2,000,000 kilowatts of nuclear power. In twenty years' time — 10,000,000 to 15,000,000 kilowatts of nuclear power, equivalent to 40-50,000,000 tons of coal a year.



The other side of the picture

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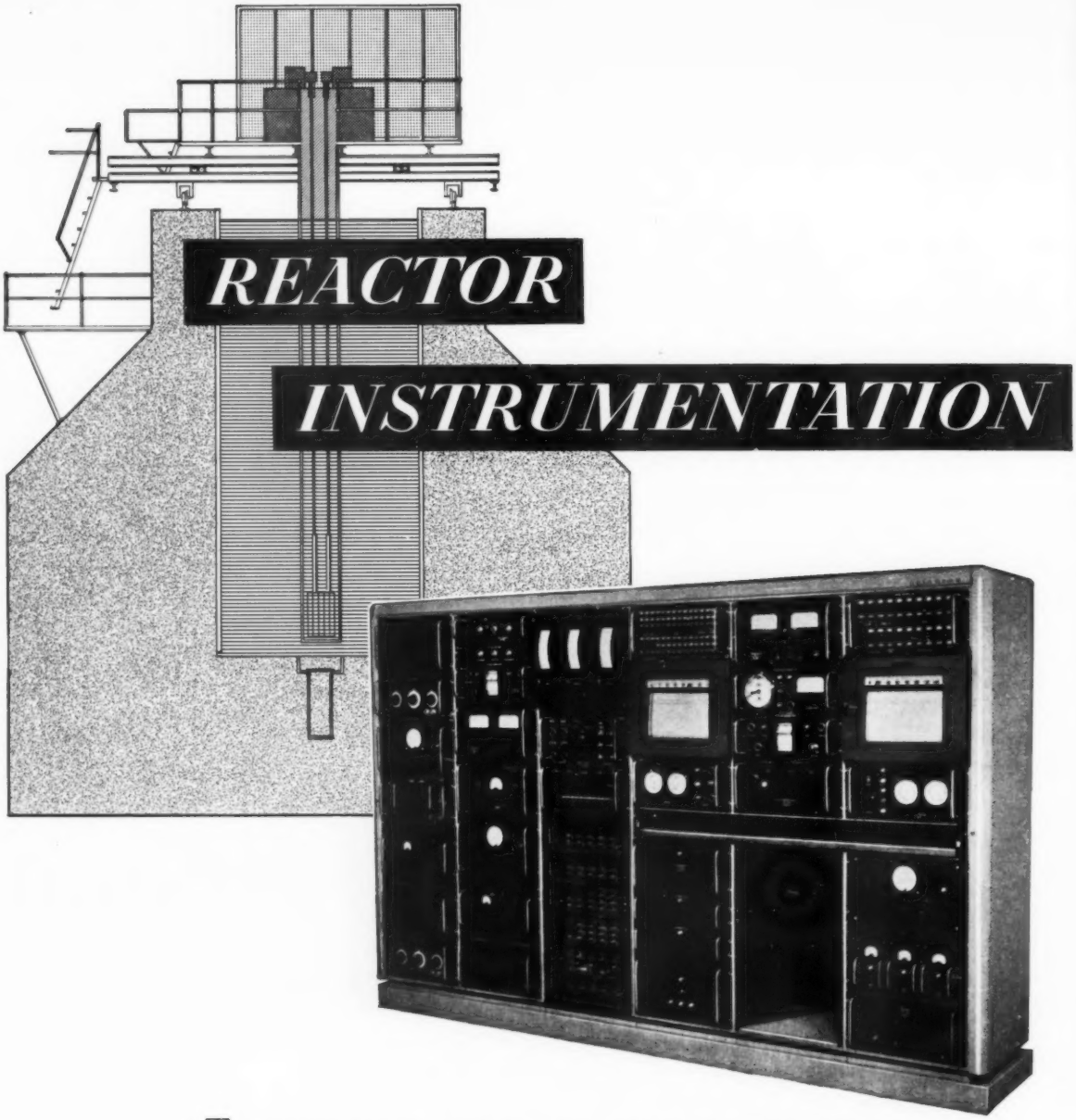

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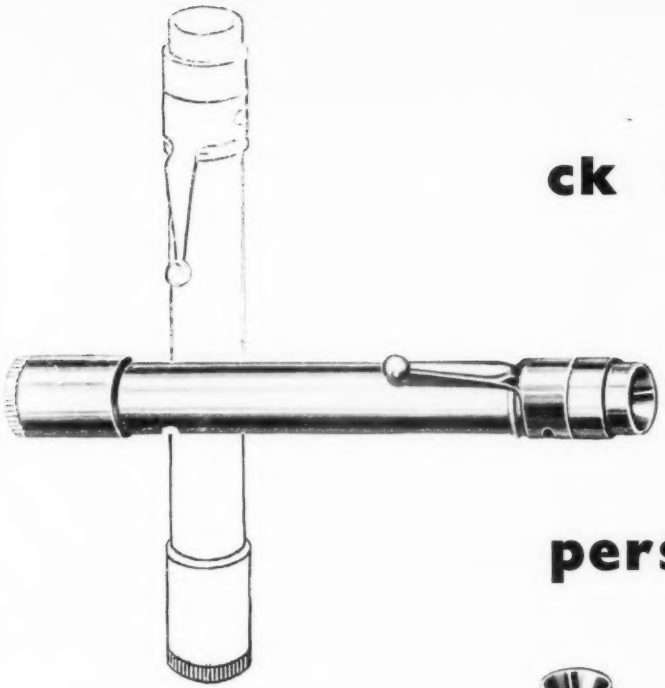

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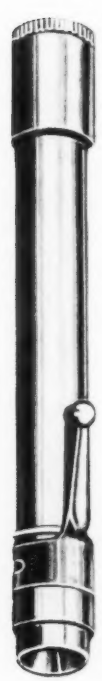

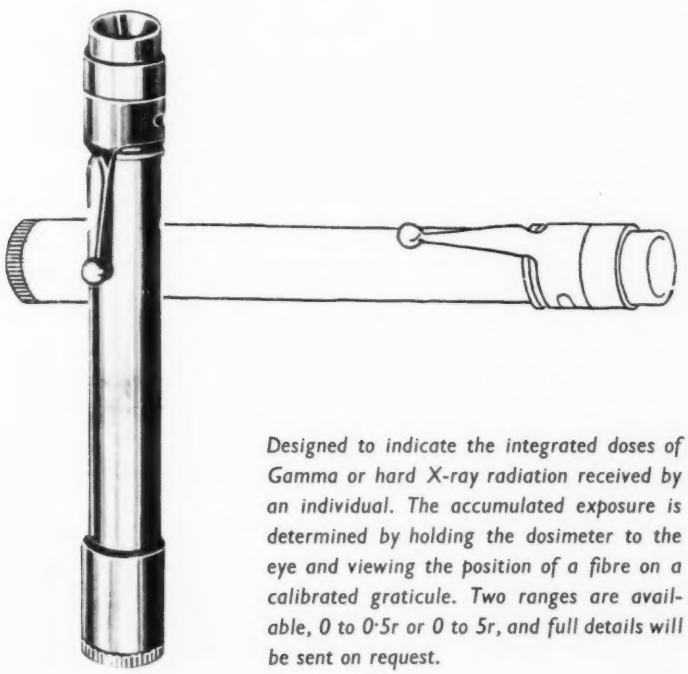

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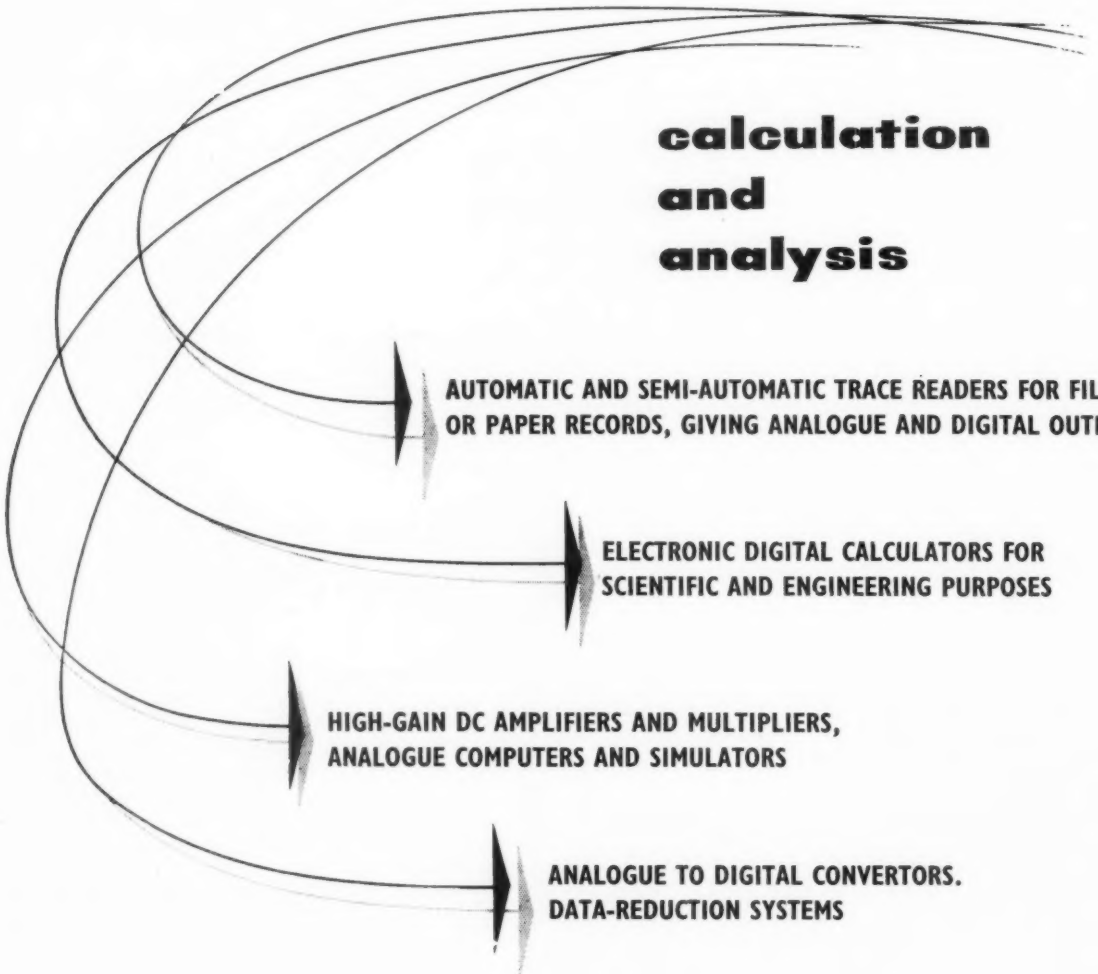
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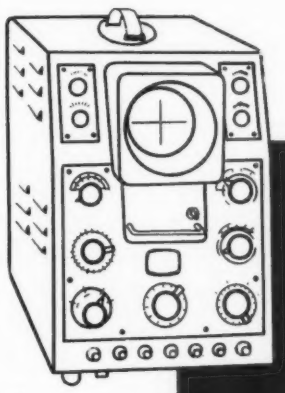

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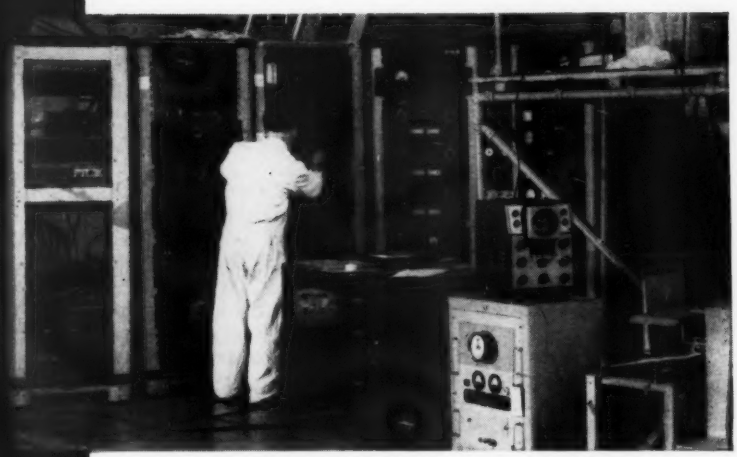

The instrument in operation near the face of the British Experimental Pile "BEPO" at the Harwell Research Establishment of the United Kingdom Atomic Energy Authority.

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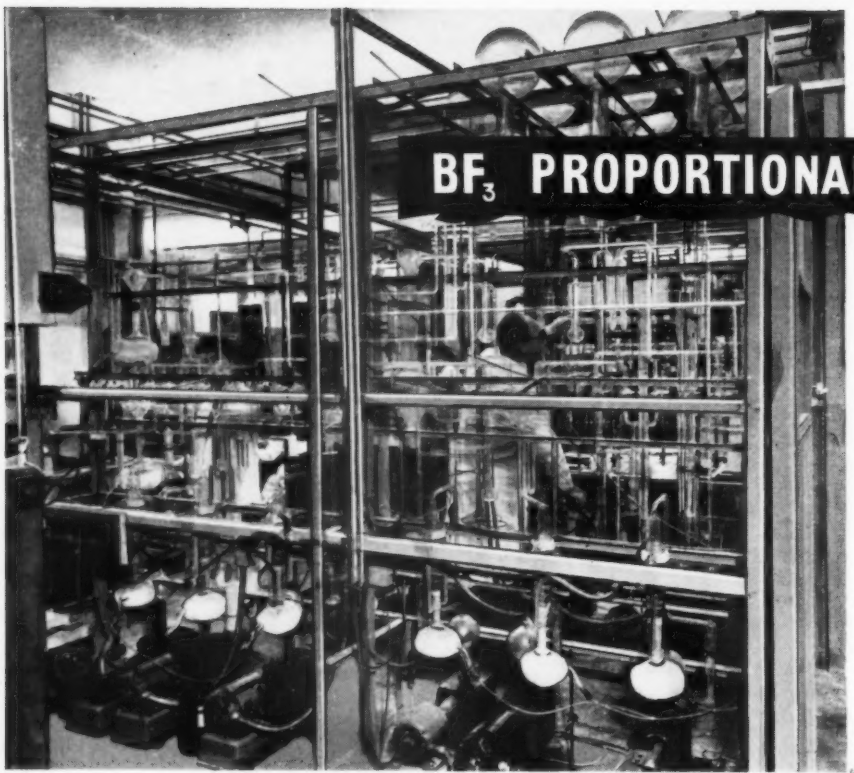
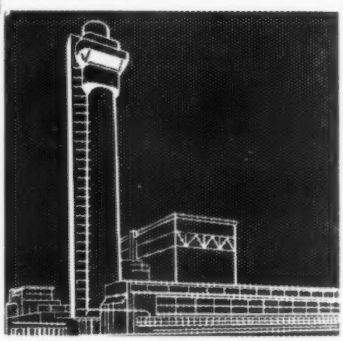


BF_3 PROPORTIONAL COUNTERS



The plant illustrated generates high purity BF_3 for counter filling. A complex (CaF_2BF_3) is first produced by a distillation process. A 30ft. distillation column for enrichment of the B^{10} Isotope has been developed under a U.K.A.E.A. contract and is in production at the 20th Century New Addington Factory.

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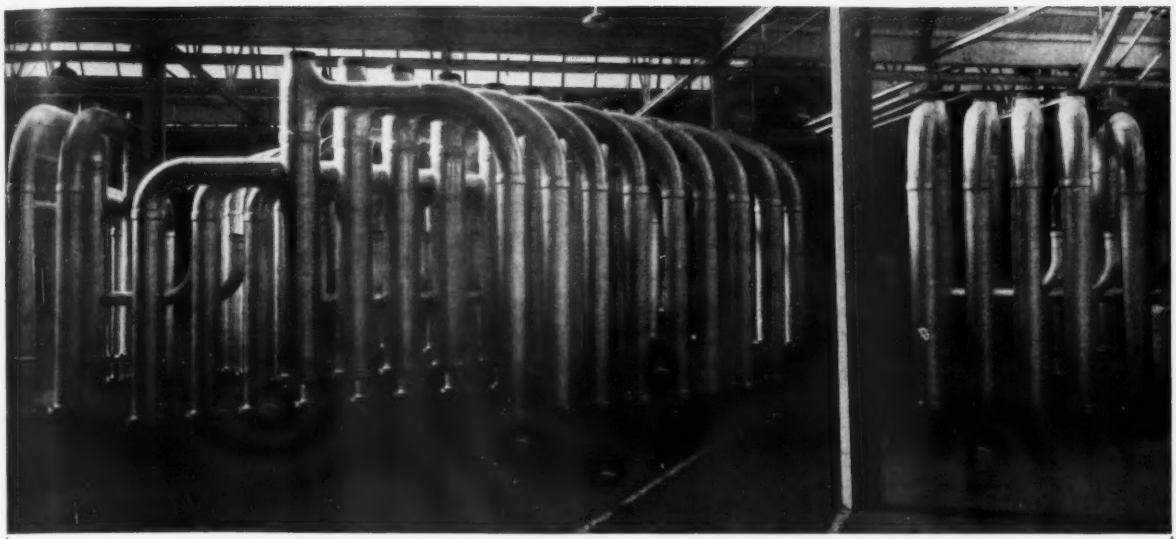

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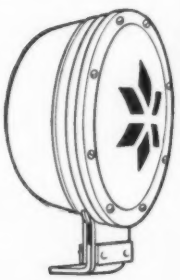

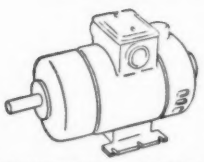

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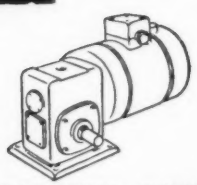

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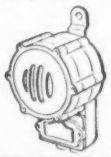

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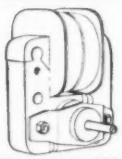

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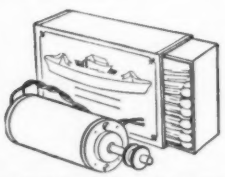

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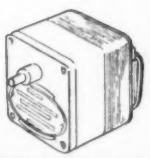

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Nuclear Power

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information sheet

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united kingdom

Last phase at Dounreay

The third and final phase of the AEA's experimental power project at Dounreay, Caithness, begins officially on Jan 1 next, according to works manager T. A. Parry speaking recently at Thurso. He said the operations team were now there and taking over sections such as the fire station, health physics department, and apprentices' buildings. 'On January 1 next year,' said Mr Parry, 'we officially take over and start up a large section of the chemical group such as the laboratory and fuel element plants as well as the laundry, canteen and main administration block, stores, workshops and surgery.' Stressing the local impact of the third phase, he added, 'Wick and Thurso men at present being trained at Windscale and Springfields will be employed as process workers at Dounreay and there are other jobs which we expect to be done by local youths after they leave school.'

The construction of the research centre at Dounreay has posed a variety of problems for Caithness Roads Committee. Heavy road transport has experienced difficulties on certain narrow routes and current plans are being directed towards elimination of these problems. A £6,000 scheme will begin shortly at Berriedale Brae, 30 miles south of Wick, where a hairpin bend has regularly dislocated heavy traffic during ice conditions.

Another scheme will cover the main road from Thurso to Reay which is also subject to heavy traffic. The AEA is contributing £61,506, the Scottish Home Department £31,332 and the County £10,442 to the total of £103,280.

No new plan yet

A revised version of the White Paper plan of February 1955 is not likely to be issued until the tenders for the first CEA stations have been studied and estimates made of what is now technically feasible in the light of experience gained in the designing of these power plants. This was made clear in the House of Commons on July 30 by the Minister of Fuel and Power, Mr Aubrey Jones, replying to questions prompted by the Suez crisis. Mr Jones said that he now regarded the White Paper as a minimum plan and that he attached the utmost importance to accelerating it as much as possible. Labour member Mr James Callaghan said there was a growing feeling that the programme for nuclear energy was moving too slowly and there was a case for speeding it up. The Minister replied that he fully accepted there was a case for speeding up but denied the present programme was in any way held up.

Harwell and gem trade

Diamonds are now to be irradiated on a commercial scale at Harwell. The object of this is to change the colour of imperfect stones by means of an effect that was first noticed over fifty years ago when it was discovered that radium had the effect of producing a colour change. Radiations from reactors and accelerators and isotopes are now to be used for this purpose, the charges to be fixed by agreement. A period in a reactor turns a stone green and subsequent heat treatment may change this to brown. In an accelerator, on the other hand, the colour is blue or bluish green. The gems acquire a certain radioactivity but this is short lived and they are safe to handle in a few days. Enquiries to: Technical Irradiation Group, Isotope Division, AERE, Harwell.

Widening the picture

Two hundred representatives from British industry are to meet Harwell scientists on Nov 30 when they will be given details of the AERE's research programme on advanced power reactors. They will have explained to them the salient features of reactors which have been chosen for detailed investigation. Following the conference, firms wishing it will be kept fully informed on progress on these reactors and this will be done at an annual conference on each reactor system. Details: Industrial Collaboration Office, Harwell.

commonwealth

India's first reactor starts

The first reactor in Asia became critical at 3.45 p.m. on Aug 4 at the Indian Atomic Research Establishment on Trombay Island, Bombay. Of the swimming pool type fuelled by British enriched uranium, the reactor was built entirely by Indian scientists and engineers in the space of only a year after design finalization. Loading commenced on July 30 but certain difficulties were experienced before criticality was achieved later in the week. Next year it is hoped to have the NRX-type reactor functioning at Trombay. This is being supplied by Atomic Energy of Canada Ltd under the Colombo Plan agreements.

soviet union

Engineers for the 5-year plan

One of the leading technological institutes in Moscow, the Molotov Power Institute, recently announced the formation of a department of nuclear power studies. Similar steps are being taken in other parts of the Union to meet the need for a large body of trained man-power to operate the nuclear power stations scheduled for construction during the current five-year plan. The first of these is due for commissioning next year and the first output of graduates from the Molotov Institute is planned to coincide with this. The Institute will have several professorial chairs and a building has been equipped as a nuclear power laboratory by Mr Malenkov's Ministry of Power Stations.

Uzbek research centre

A nuclear physics institute is to be set up at Tashkent in Uzbekistan under the control of the Academy of Sciences of the Uzbek SSR by a recent order of the Council of Ministers of the USSR. As well as fundamental research, the institute will carry out work on isotope applications to biology, chemistry, medicine and industry. Its equipment will include a re-

search reactor housed in a special building. Uzbekistan is already an important scientific centre of the USSR and extensive atomic research work has already been carried out there.

east europe

Soviet aid for Hungary

Hungary can produce enough uranium to cover all electric power requirements for many decades, Prime Minister András Hegedüs told a Budapest press conference last month. Replying to questions he said: 'We shall start building the first atomic power station next year There is a possibility that Hungary will precede many industrially developed Western countries in establishing atomic power stations. In April Hungary stated its intention to begin the mining and processing of uranium ore during the next 'few years.' Work began three months ago on an atomic research station in Budapest, aided by Soviet technicians and technical help. Isotope production at the station—a three-storey red-brick building in Liberty Hill overlooking the capital—will begin at the end of next year or the beginning of 1958 according to plans.

france

First "power only" station

Construction of the first big nuclear power station in Europe optimised solely for electricity generation started recently at Chinon, near the junction of the Loire and the Vienne. Electricité de France's first reactor, EDF-1 as it is known, is to have an installed capacity of 60MW and is due for completion in 1959. It will be followed in about 18 months by a second station, EDF-2. EDF's programme envisages the installation of between 3 and 6 million kW by 1975.

Oil firm buys accelerator

The Compagnie Francaise de Raffinage, a leading French petroleum refining and processing organization, announced in Paris recently the purchase of a 2-million-volt Van de Graaff particle accelerator from High Voltage Engineering Corp., Cambridge, Mass., U.S.A.

belgium

Belgian engineers in US

Three key members of Belgium's top-level atomic energy team are at present with Nuclear Development Corporation of America (NDA) at White Plains, N.Y. They are Henri Dopchie, Jacques Planquart and François Van Geertruyden, members of the staff of the Centre d'Etudes pour les Applications de l'Energie Nucleaire, Mol, and are assigned to duty in connection with Belgium's engineering test reactor, now in the early stages of design.

switzerland

ISO and nuclear energy

National standards required for the peaceful development of nuclear energy are to be unified internationally as swiftly as possible according to a decision taken by the Council of the International Organization for Standardization at its recent meeting in Geneva. Standardization between countries would aid exports and speed the flow of scientific and technical information, say the British Standards Institution in making this announcement. ISO's technical committees are to consider the fields of (1) terminology, definitions and symbols (2) safety standards for protection against radiation hazards (3) standards for the safe and effective operation of reactors. Close cooperation will be maintained with the International Electrotechnical Commission (IEC)—which has formulated its own plans in the electrical field.

germany

Details of London Agreement

The agreement signed in London on July 31 by ambassador Hans von Herwarth and UK foreign minister Selwyn Lloyd is for ten years and allows Germany to obtain in Britain, on terms to be agreed, research reactors, fuel elements and unclassified information on topics to be agreed concerning the design, construction and operation of these reactors. Training is also covered in the agreement and the UKAEA will provide facilities for German scientists to study at Harwell. Safeguards in the agreement are included to ensure that the materials and information will be used only for peaceful purposes. Both countries reaffirm their support for the International Atomic Agency when it is set up. Minister for Atomic Affairs Franz Joseph Strauss and AEA chairman Sir Edwin Plowden were present at the signing in London.

RWE to buy power reactor

It has been confirmed that Rhein Westfälische Elektrizitätswerke intends to buy an experimental reactor at a cost of between 20 and 30 million DM, according to chairman Schöller who added that offers had been received from Britain and America. The offers are understood to have come from Siemens-Schuckert in cooperation with Westinghouse, from Brown Boveri and from AMF Atomics and Mitchell Engineering in the UK. RWE's intention is to gain experience with a view to building a 700-1000 MW plant in about ten years' time.

Atomic minister Franz Joseph Strauss recently stated that the Federal programme envisages an installed nuclear capacity of 2·8 to 3 million kW by 1975.

scandinavia

British instruments on show

Thirty-four instrument firms of the Scientific Instrument Manufacturers' Association, acting in collaboration with the Board of Trade, are displaying examples of British instrumentation in the fields of optics, laboratory apparatus, electrical, electronic and nucleonic equipment and measuring instruments at the St. Eriks Fair, Stockholm, which began on Sep 1. It will remain open until Sep 16. The British area covers 5,000 sq. ft. The participation at St. Eriks on such a large scale will earn enormous prestige for this important industry and help to foster new markets in Sweden and other Scandinavian countries.

Thickness gauges for measuring, recording and controlling the thickness of sheet materials such as paper, cardboard, plastics, rubber, metals, linoleum, etc., are of particular interest to the Scandinavian countries, as are also static charge detectors which measure electrostatic charges in the paper, plastic, rubber and explosive industries as well as in hospital operating theatres. There are also gauges for measuring variations in weight of paper and plastics across the web.

Among a selection of nucleonic instruments will be various ratemeters, dosimeters, radiation monitors, ionization chambers, isotope containers for industrial radiography and flaw detection equipment for quality control.

far east

Japanese atom centre

Last month chairman Matsutaro Shoriki of the Atomic Energy Commission initiated building at a small village, Tokai-Mura, about 75 miles north of Tokio where the Japanese atomic research centre is to be set up. Mr Shoriki told the visitors at the ceremony that the current 15-year plan involved about eight reactors. The first ones are to be a water boiler and a CP5 to be bought from the United States. There will also be a natural uranium, heavy water reactor which they would build themselves. Japan's current appropriation for nuclear energy development is £3·6m and the Commission is to ask for this to be raised to £12m for 1957.

united states

Whither the AEC?

Interest in plutonium-fuelled reactors is developing rapidly according to the 20th semi-annual report of the Atomic Energy Commission, published in Washington last month. The General Electric Hanford works has been requested to plan a development programme centred on a small experimental reactor using plutonium fuel elements. Combination of plutonium with natural uranium would free most countries from dependence on imported U-235, says the report. Meanwhile, at Los Alamos a molten plutonium fast reactor is under consideration although progress is not expected to be rapid.

Some findings of the accident to EBR-1 at Argonne are reported. On Nov 29 a reactivity excursion occurred and, owing to misunderstandings, the reactor was not brought subcritical quickly enough. Not until May 17 was it possible to remove the core from the pressure vessel and it was then found that the temperature had exceeded 1130°C, the melting point of uranium. Valuable experience has been gained from the incident which is claimed to show that even a substantial melting did not result in an explosion and that radioactive products were easily contained.

SRE at Santa Susana in California has suffered various setbacks but it is now believed that criticality trials will commence in January. HRE-2 at Oak Ridge was completed in May and criticality tests are due to start any time now. BORAX 3 at NRTS, Arco, was shut down in April after running for 6 months at a power level equivalent to 2000 kW electric. A new core is being installed and the reactor has been renamed BORAX 4. The next step in the boiling reactor programme is the completion of Argonne's EBWR which is expected to be in operation next year.

Under development at Knolls (General Electric) is a new submarine advanced reactor, designated S3G. Two of these are to be used in the Navy's picket submarine which will be the largest underwater craft ever constructed. A small submarine reactor, S1C, is the subject of a development contract awarded to Combustion Engineering to be carried out at a new test facility at Windsor, Conn.

The independent industrial reactor programme now numbers five approved projects: Consolidated Edison, Indian Point, PWR, 140 MW; Commonwealth Edison and others, Dresden, I11, BWR, 180 MW; General Electric and Pacific Gas & Elec., San Francisco, BWR, 3 MW; Pennsylvania Power & Light, aqueous homogeneous, 150 MW; Florida Power Corp. unspecified, 200 MW. The first contract of the Government assisted Power Demonstration Reactor Programme was signed on June 6 with Yankee Atomic Electric Co for the 134 MW PWR at Rowe, Mass. Two others are in negotiation: Consumers Public Power District of Columbus, Nebr. for a 75 MW SGR and with Power Reactor Development Co Inc for a 100 MW boiling reactor at Dresden, Ill. In addition, seven other proposals have been received from various public utilities. These are for comparatively small plants but include interesting types of reactors such as: sodium-cooled, heavy-water-moderated; nitrogen-cooled; organic-moderated and liquid fuel.

The total installed electrical capacity of approved plants in the three programmes now totals 1,182 MW. This is made up as follows: Government Experimental Programme, 90 MW; Power Demonstration Programme, 419 MW; Independent Industrial Programme, 673 MW. The total estimated cost to the Government is $313m: to Industry it is $358m. It should be noted that except for the PWR at Shippingport which is due critical next year none of these large power stations will be in operation before 1960—1962 in some cases.

Differences in the Commission were later voiced by Commissioner Thomas E. Murray who declined to subscribe to sections of it. Mr Murray did not accept the assertion that the programme had gone forward on a broad front and he averred that it was stagnating because of a belief that the United States did not need nuclear power urgently. While Britain and the USSR, he said, would have economic power stations by 1960, there was at present little likelihood of the United States having them. Commissioner Murray also disagreed with his colleagues on their estimation of the hazards from strontium fallout arising from bomb tests.

Private fast breeder

A 100-MW, electric, fast breeder is to be built at Monroe, Mich, by

the Power Reactor Development Company of Detroit—a group of 26 public utilities and industrial firms. The plant is estimated to cost $40m and the output will be fed to the Detroit Edison grid. The group obtained AEC approval for the plant on Aug 3 but before it is handed over for operation, the Commission is to carry out stringent acceptance tests to ensure that public health and safety are not endangered. An AEC spokesman said that the Commission considered the fast breeder programme very important and would assist the group in resolving safety problems.

At a ground breaking ceremony on August 8 at the Lagoona Beach site on the Lake Erie shore, the Power Reactor Development Company stated that the plant would be known as the Enrico Fermi Atomic Power Plant in honour of the famous Italian physicist who constructed the world's first self-sustaining nuclear chain reaction in Chicago in 1942, and who died in 1954.

Battelle's new lab ready

The critical assembly laboratory at the Battelle Memorial Institute in Columbus, Ohio (NUCLEAR POWER May) has now been completed and is currently being readied for research work on reactors for land, sea and air applications. This is the second unit of Battelle's Atomic Energy Centre to come into operation.

Caesium process at ORNL

Oak Ridge National Laboratory recently announced a new process for the recovery of caesium-137 from fission products, and a pilot plant is now under construction. The final product is in the form of a compressed caesium chloride pellet weighing 3.21 ounces and measuring 1.25 in. dia., 1.47 in. long. Three pellets are contained in a double-walled stainless steel capsule, forming a 2000 curie source. According to Operations Division director Arthur F. Rupp, the pilot plant will be in operation next June and should have a throughput of 200,000 curies a year. This will reduce significantly the present price of about $14 a curie. In addition to caesium, Oak Ridge are planning to produce strontium-90, cerium-144, promethium-147, tecnetium-99 and ruthenium-106.

Two years ago, Oak Ridge, which is operated for the AEC by Union Carbide and Carbon, produced a 1540 curie caesium-137 source which is now in use at the Oak Ridge Institute of Nuclear Studies. The first 2000 curie source will be used at the University of Michigan for further studies in fission products.

New prices for carbon-14 and iodine-131 were announced by the AEC in Washington on August 24. C-14 now costs $28 a millicurie for shipments of 199 or less: over this it is $22. I-131 is now 50 cents a millicurie for lots of 499 or less: 40 cents for more. Since C-14 was first supplied in 1946, more than 2200 consignments have been made. Simultaneously with the AEC announcement, Atomic Industrial Forum said that 1000 US industries are now using isotopes in 1347 different plants.

Flat out for 66 days

In a test concluded on August 8 the STR Mk I reactor (the land-based prototype of that used in the submarine USS *Nautilus*) was run non-stop at 100 per cent. output for 66 days, or 1660 hours. The test took place at the National Reactor Testing Station at Arco, Idaho, and was designed to prove the reliability of pressurised water reactors for ship propulsion. The reactor—now renamed S1W—was refuelled in March after 2½ years operation on the original core and still has many hundreds of hours of full output available, says the AEC announcement making this news. The reactor has now resumed operation at varying power levels in order to obtain engineering data and to provide training facilities for officers and men of the US Navy.

The AEC point out that if the *Nautilus* herself had steamed for this period she could have travelled submerged at top speed—about 18 knots—round the world and many thousands of miles more. A diesel-powered submarine cruising the same distance would have used about 1·6 million gallons of fuel.

The test is claimed to be the longest non-stop full power run ever completed by any type of propulsion plant—land, sea or air.

Zinn for Industry

Former Argonne National Laboratory Director, Walter H. Zinn recently became president of the newly-formed General Nuclear Engineering Corporation of St. Petersburg, Fla. GNE is to provide engineering and other services in connection with the design, construction and operation of reactors and other atomic energy facilities. Research and development services are also offered.

Associated with Dr Zinn in GNE are three erstwhile Argonne colleagues—Harold V. Lichtenberger, previously in charge of Argonne's facilities at the Idaho test station; John M. West, who headed the EBWR group; and physicist Joseph R. Dietrich, responsible for the theoretical work on the STR and the Argonne boiling reactor experiments. It will be seen that Argonne have lost a quartet of its top-flight men and that GNE have assembled a formidable team of specialists.

Ship project approved

One of the last acts of the 84th Congress was President Eisenhowers' authorization on July 30 of the first atomic-powered merchant ship. It has not yet been decided whether the vessel is to be a liner, a freighter or a tanker but the President's directive stipulates that it must be capable of operating on main trade routes. The Maritime Administration is to plan and construct the hull while the AEC is to look after the power department. It is noted in the AEC semiannual report that a large ship reactor, the A1W, is under development at Westinghouse's Bettis plant in Pittsburgh. The ship is expected to cost $42.5m.

Speaking in Washington before the Presidential decision, Federal Maritime Board chief, Clarence G. Morse said it was hoped to have the ship in operation by 1960. In reply to questions he admitted it would not be economic but thought that nuclear powered merchant ships might become profitable in about ten years.

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Nuclear Power
SEPTEMBER 1956 VOLUME I NUMBER V

Why only electricity?

IN THE MINDS OF most people, nuclear power means ultimately electricity generation, and certainly this is the form in which the energy released by fission will first be manifested. We, in this country, are on the very threshold of this new source of electrical energy and in just over a month we shall have crossed it. In the general picture of world energy requirements, however, electricity plays quantitatively only a minor, although indispensable, role, for of the equivalent of $10{\cdot}2 \times 10^9$ MWh of energy usefully put to work throughout the world in 1952, only 2·1 were in the form of mechanical or electrical power, the balance of 8·1 units being in the form of heat. Of this, 5·2 units were used in industry and 2·9 in households for space heating, water heating and cooking. Details of the pattern vary from country to country but the tendency is clear.

At present, much reactor research is being directed towards achieving higher temperatures and this is wholly admirable since the thermal efficiency of any heat engine is dependent on the initial temperature. But there is obviously a vast potential demand for low temperature heat for industrial processes, space heating and domestic purposes, so a good case exists for reactors operating at quite moderate temperatures. Even from large central power stations there is a strong economic argument for dual-purpose plants producing both electricity and heat from back-pressure or pass-out turbines. Some sacrifice in turbine efficiency is inevitable with this arrangement, but when the heating is taken into account, combined efficiencies of over 80 per cent. are possible and are in fact being achieved from the two small (1350 kW) back-pressure sets at Battersea power station which supply heating for about 11,000 persons in the Pimlico scheme. Pimlico is admittedly rather a special case since the distribution problem was made easy by an entirely fortuitous set of circumstances and so far the leading argument against district heating in this country hangs on the apparently high cost of the distribution system.

We are brought up to believe that we live in a temperate climate and so, as a nation, we tend to look on central heating as somewhat effete and cling obstinately to the open coal fire as our primary source of warmth in the home. But in view of the fact that the price of coal is increasing steadily at the rate of 1·2 per cent. per annum compound (doubling in 60 years) in relation to wholesale prices generally, it may fairly be assumed that coal will, in the course of time, lose its attractiveness.

It is encouraging to note that Sweden is already working on nuclear heating stations and that Norway is developing the use of nuclear heat for the wood pulp and paper industries. It should also be remembered that we in this country were the first to use a nuclear reactor for space heating—in the BEPO installation at Harwell. A much more sophisticated heating installation was recently completed at the Hanford plant of the USAEC. The technical problems of district heating from nuclear sources—either heat only, or dual purpose—are not difficult and one feels that if a real effort were devoted to the question of distribution this, too, could be made an economic proposition in suitable locations. Presenting the United Nations report on World Energy Resources at Geneva, Mr. Guyol said: 'If during the next half-century, nuclear science is directed solely towards the production of electric power, no more than one-fifth of the world's energy will be obtained from nuclear sources by the year 2000. If, on the other hand, this new branch of science is directed towards the production of low-cost heat, as well as electric power, nuclear fuels could provide as much as three-quarters of the 84 thousand million megawatt-hours of energy that we believe will be required in the year 2000.' The first thing is obviously to obtain electricity, for its distribution is a comparatively simple and well-understood technique: in the planning of future power stations, however, we should consider most seriously the question of the bulk distribution of heat as such, because long after nuclear electricity is commonplace, coal will still be needed as a basic raw material and by then will have become far too expensive to use as a fuel.

At Harwell, physicists, chemists and metallurgists are carrying out a vast research programme which will enable the engineer to build better power reactors

Scientific problems in the development

ALTHOUGH THE DESIGN of the first CEA stations will be a substantial advance on Calder Hall there is still great scope for research and development leading to further improvement of the gas-cooled graphite-moderated reactor. Later types of nuclear power stations using other kinds of reactors present a still wider range of scientific problems. These divide conveniently into problems of reactor physics, solid state physics, and chemistry.

1 Reactor physics problems

1.1 Core Structure

The first problem to be considered in designing a new type of reactor is to determine the optimum parameters of the core. After this, exponential experiment assemblies or zero energy critical assemblies are made to establish the general nuclear characteristics of the reactor system, and it is then possible to combine the nuclear calculations of the core together with heat transfer and economic analysis to design the best reactor. The design may be finally checked by a further zero energy experiment.

This procedure applied to the gas-cooled graphite-moderated reactor led to a lattice pitch of about 8 in. and a uranium rod diameter of about one in. The graphite has a cross-section of about 4 millibarns, and the canning material is a magnesium alloy—magnox. Heat extraction rates of about 3 megawatts (thermal) per ton are expected to be achieved in future.

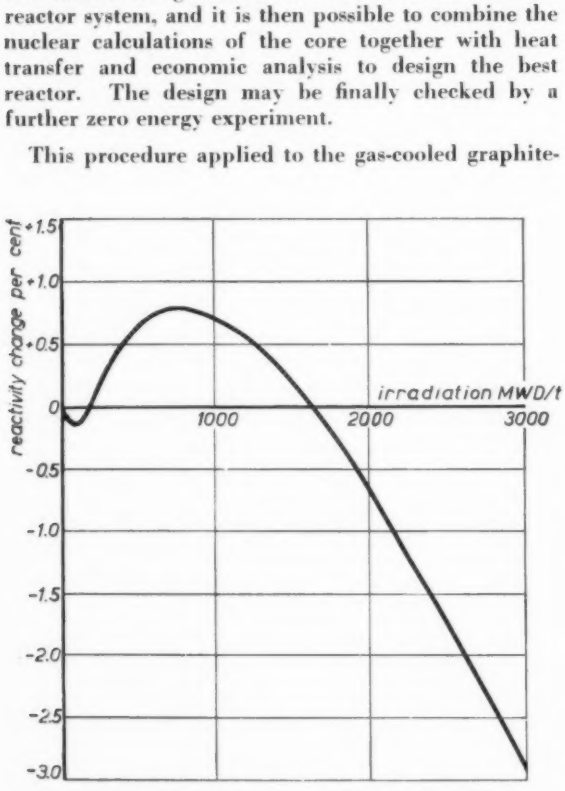


Fig. 1 *reactivity variation with irradiation for a uniformly irradiated Calder type reactor*

An important parameter of the core is the conversion factor of U-235 to plutonium since this is one of the most important factors determining long-term reactivity changes. A typical neutron balance sheet of a good gas-cooled graphite reactor is as follows—the conversion factor is about 0·85.

yield	U^{235} *and* U^{238}	2.10
absorption	U^{235}	1·00
	U^{238}	0·85
	Graphite	0·12
	Parasitic (i.e. Sheaths, Xenon and control)	0·08
leakage		0·05
absorption and leakage		2·10

1.2 Reactivity changes

The fuel costs in power reactors are determined by the price of uranium, the cost of fabricating fuel elements, the burnup which can be achieved per cycle and the value of the spent fuel. The achievable burnup depends on the course of the reactivity changes (Fig. 1). There is an early drop of reactivity due mainly to the formation of samarium-149, followed by a rise due to the conversion of U-235 to plutonium-239. The greater the conversion factor, the greater the increase of reactivity.

As the burnup proceeds past 1000 megawatt days per ton (MWD/t) the conversion of plutonium to higher isotopes Pu-240 and Pu-241 becomes important. Pu-240 is not fissile by thermal neutrons but is converted to form Pu-241 with an absorption cross-section of about 1200 barns. Pu-241 has a fission cross-section of about 1000 barns and a cross-section for capture to form Pu-242 of roughly 500 barns for thermal neu-

# of nuclear power

by Sir John Cockcroft KCB, CBE, FRS
Director, AERE, Harwell

trons. These cross-sections are not yet known accurately enough: so far they have been determined at Harwell by using plutonium with up to 50 per cent of Pu-240. Fig. 2 shows the isotopic constitution after burnup.

Another important factor in determining long-term reactivity changes is the effect of fission products of long half-lives. We do not know these cross-sections with sufficient accuracy and are now starting an experimental programme to improve our knowledge. A programme of this kind requires special facilities and involves a great deal of work. Even to cut up an irradiated plutonium rod into sections having activities of thousands of curies requires good remote-handling devices, whilst the cell for separation of the fission products has to be heavily shielded and equipped with remote handling.

The operation of reactors at temperatures adequate to produce power requires a knowledge of nuclear constants at neutron energies higher than thermal. We expect to improve the accuracy of our measurements and to extend the range of these by two new developments at Harwell. The first will make use of a neutron beam from the DIDO reactor. This will give us 40 times higher intensity than we have had from BEPO. A new fast chopper operating at 48,000 rev/min is being built for this work and a flight path of 100 metres will be used.

1.3 Fuel cycles

Another important factor in determining the burnup in a particular reactor is the cycle of fuel element change. The ideal method is to discharge the fuel elements quasi-continuously which can be achieved if the design provides for charge and discharge to be carried out whilst the reactor is operating.

Since the irradiation of the fuel in the central zones is more intense these are the first to be discharged, followed by discharge of zones proceeding outwards. In general, burnup can proceed until the area below the reactivity curve equals the area above the curve in the early part of the irradiation.

When continuous charge and discharge is not possible, operational procedure may lead to discharge by zones, so that the maximum of irradiation of individual fuel elements may vary appreciably. This reduces the average burnup.

With our present inadequate knowledge of nuclear constants, estimates of burnup are uncertain by perhaps 500 MWD/t. The achievable burnup depends on

SCIENTIFIC PROBLEMS SURVEYED are those of reactor physics, solid state physics and chemistry. The prospect of high burnups and the conversion of plutonium-239 to Pu-240 and Pu-241 has led to a study of these isotopes. Slight enrichment of fuel for gas-cooled, graphite-moderated reactors is believed to be economical and burnups of 10,000 MWD/t are expected ultimately. On fast plutonium reactors, breeding gains of 1·6 to 1·7 are expected. The most difficult problem is the development of a reliable fuel element, but radiation problems of great difficulty occur with all reactor materials. Compatibility problems between fuels, moderators, and coolants are discussed and a new aluminium alloy is reported. Pyro-metallurgical methods for the processing of irradiated elements show promise and will probably be used for fast reactors.

L'ARTICLE CONTIENT UN APERCU des problèmes scientifiques relatifs à la physique des réacteurs, physique des corps solides et chimie. La perspective d'atteindre des hautes consommations et la transformation du plutonium-239 en Pu-240 et Pu-241 ont mené à l'étude de ces isotopes. On admet qu'un faible enrichissement du combustible pour les réacteurs refroidis par l'air et modérés au graphite est économique, et l'on prévoit des consommations finales de 10000 MWD/t. On prévoit des gains de régénération de 1,6 – 1,7 dans les réacteurs au plutonium à neutrons rapiaes. Le problème le plus difficile est celui de développer un élément combustible sûr; néanmoins, on rencontre des problèmes de radiation très difficiles relatifs à tous les matériaux employés dans les réacteurs. On discute les problèmes de compatibilité entre combustibles, modérateurs et réfrigérants, et l'on décrit un nouvel alliage d'aluminium. On est optimiste en ce qui concerne les méthodes de pyro-métallurgie pour le traitement des éléments irradiés et l'on espère que ces méthodes seront employés pour les réacteurs à neutrons rapides.

ES WIRD EIN UBERBLICK der wissenschaftlichen Probleme der Reaktorphysik, Festkörperphysik und Chemie gegeben. Die Aussicht hoher Brennleistungen und die Umwandlung von Plutonium-239 in Pu-240 und Pu-241 führte zum Studium dieser Isotope. Man vermutet, dass eine geringe Anreicherung des Brennstoffs für gasgekühlte Reaktoren mit Graphitmoderatoren wirtschaftlich ist, und es werden Höchstbrennleistungen von 10000 MWD/t erwartet. In Plutonium-Schnellreaktoren werden Brutgewinnste von 1,6 – 1,7 vorgesehen. Das schwerste Problem ist die Entwicklung eines zuverlässigen Brennstoffelements, doch begegnet man äusserst schweren Strahlungsproblemen im Zusammenhang mit sämtlichen Reaktorbaustoffen. Es werden Verträglichkeitsprobleme zwischen Brennstoffen, Moderatoren und Kühlmitteln erörtert, und es wird über eine neue Aluminiumlegierung berichtet. Pyrometallurgische Verfahren für die Bearbeitung von bestrahlten Elementen sind vielversprechend und werden dieselben wahrscheinlich für Schnellreaktoren angewandt werden.

LOS PROBLEMAS CIENTIFICOS examinados son aquellos de la física del reactor, física del estado sólido y química. Las posibilidades de "quemas" de gran intensidad y la conversión de Pu-230 en Pu-240 y Pu-241 ha conducido a un estudio de estos isótopos. El ligero enriquecimiento del combustible para reactores enfriados por gas y moderados con grafito se cree que resulta económico y finalmente se esperan "quemas" de 10,000 MWD/t. En reactores de plutonic rápidos se anticipan aumentos de reproducción de 1,6 a 1,7. El problema más difícil consiste en el desarrollo de un elemento combustible seguro, pero con todos los materiales del reactor se presentan inconvenientes muy difíciles. Se discuten los problemas de la compatibilidad entre combustibles, moderadores y enfriadores, y se menciona una nueva aleación de aluminio. Los métodos pirometalúrgicos para la elaboración de elementos irradiados son prometedores y, probablemente, serán utilizados para reactores rápidos.

ОБОЗРЕВАЮТСЯ НАУЧНЫЕ ПРОБЛЕМЫ физики реакторов, физики твердых тел и химии. Перспективы больших расходов сгорания и превращение плутония-239 в Pu-240 *и* Pu-241 *привели к изучению этих изотопов. Полагается, что незначительное обогащение топлива для реакторов с газовым охлаждением и графитовым замедлителем будет экономично; предвидятся в будущем величины сгорания в* 10000 MWD/t. *Имеется надежда, что избыточный коэффициент воспроизводительности ядерного топлива в плутониевых реакторах на быстрых нейтронах достигнет величины* 1,6—1,7. *Самой тяжелой проблемой является осуществление надежного топливного элемента; однако весьма тяжелые проблемы, связанные с излучением, встречаются для всех реакторных материалов. Рассматриваются проблемы совместимости между топливом, замедлителем и охладителем, а также описывается новый алюминиевый сплав. Пирометаллургические методы обработки облученных элементов подают большие надежды и, кажется, будут употребляться в реакторах на быстрых нейтронах.*

the neutron economy and particularly on the initial conversion factor. A graphite-moderated reactor of this type likely to be used in future power stations is likely to achieve a burnup of 2500-3000 MWD/t.

An important corollary to this is that slight enrichment of the fuel of graphite moderated reactors is likely to be economical. Comparatively small enrichment to increase the proportion of U-235 by three or four per cent will increase reactivity and allow the burnup to be increased. The cost of this may be estimated by taking the USAEC price of U-235 as a basis. A 3 per cent enrichment requires 215 grams of U-235 per ton of metal, so that the added cost at $25,000 per kilo is about £1,900 per ton of metal. This would add about 10 per cent to the cost of fuel elements. If the additional burnup exceeds this increased cost of 10 per cent appreciably, slight enrichment would be advantageous.

Additional burnup of fissile material in thermal reactors should be achievable by recycling the plutonium together with the greater part of the depleted uranium and feeding into the system a quantity of natural uranium to make up for the U-235 burnt. In the equilibrium condition the content of the different fissile isotope in the reactor stays approximately constant since as much plutonium is produced as is destroyed by fission.

We expect that a gas-cooled graphite-moderated reactor with a conversion factor of 0·8 and an operating temperature of 400°C could achieve an overall burnup of the order of 10000 MWD/t.

The burnup likely to be achieved in an enriched fuel reactor such as the sodium-graphite, which we are studying, is likely to be markedly less, especially if the reactor is operated at temperatures of about 500°C for this will lead to η falling to 1·65-1·70. The value of the conversion factor will of course depend greatly on the design and particularly on how much neutron-absorbing material such as zirconium is introduced into the core for graphite canning. It will also depend markedly on the reactor size and output. Until design parameters have been specified we cannot therefore predict burnup accurately. Nevertheless at this stage of investigation it appears that the sodium graphite reactor should be operated on the U-233/thorium cycle if good burnup is to be achieved.

An alternative way of achieving high burnup has been pointed out by Dr. W. B. Lewis. He suggested that U-235 should be burnt in reactors of high conversion ratio (0·9) such as heavy-water reactors and that by using the U-233/Th cycle with thorium oxide fuel elements, burnup of well over 10000 MWD/t should be achieved. At US prices of U-235, fuel costs could be reduced to the order of 1 mil.

1.4 Fast reactors

The problems of reactors using the upper end of the fission neutron spectron are completely different from those of thermal reactors.

The computation of critical core sizes by purely mathematical methods at first led in the UK to results which were uncertain to ± 25 per cent. Since that time we have constructed two zero energy reactors, ZEPHYR and ZEUS, fuelled by plutonium and U-235 respectively and our knowledge of the behaviour of fast reactors has greatly increased.

Important measurements have also been made on the variation of the fission rates throughout the core and blanket, in Pu, U-235 and U-238. It was found that the fission of U-238 contributes in an important way to the neutron economy of the reactor. The overall result was that in the uncooled, undermoderated ZEPHYR, breeding gains of over two were obtained. In a future high-powered plutonium fast reactor, the achieved breeding gains are likely to be between 1·6 and 1·7. ZEPHYR work has recently shown that with a Pu core and thorium blanket, 1·6 atoms of U-233 are formed for each Pu atom destroyed.

3 Problems of solid state physics

Problems of solid state physics or metallurgy are even more important than those of nuclear physics: the most difficult of all is the development of a reliable fuel element.

The first commercial graphite-moderated gas-cooled reactors will operate with fuel element surface temperatures somewhat over 400°C and central metal temperatures below the alpha-beta change point of 665°C. Sodium-graphite reactors and fast reactors will probably have metal surface temperatures of 500°C, whilst future reactors depending on cermet or oxide fuel elements may operate at much higher temperatures.

The study of radiation damage in any new set of circumstances may require a total effort of at least 200 man-years. A good deal of this goes into the preparation of specimens having different alloy constitutions and different heat treatments. Loops have to be prepared for containing and cooling the specimens in a testing reactor. These loops have to be provided

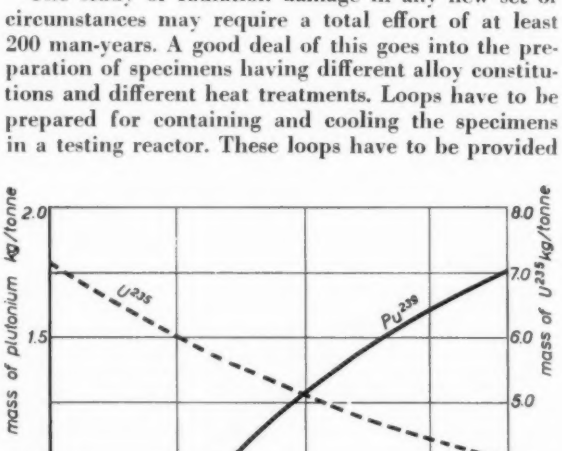


Fig. 2 ***isotopic composition of irradiated natural uranium in the Calder type reactor***

with thermostatically controlled temperature conditions.

After the irradiation, the specimens are highly active and must be examined by remote viewing behind thick concrete walls and handled by remote control. For this purpose, television has been used successfully at Harwell.

Low temperature radiation damage can lead to severe distortion of uranium. We are still very far from understanding this phenomenon though it undoubtedly results from the complicated orthorhombic crystal structure. The large-scale effects can cause a uranium rod to stretch in length or to shrink several inches depending on crystal orientation (Fig. 3). A single crystal of uranium changes its shape markedly under radiation, just as though the uranium atoms flowed through the crystal stimulated by the local heating due to the high speed fission fragments. The immediate solution for uranium fuel elements to be operated at temperatures of the order of 400°C is to heat treat the metal so as to reduce the grain size and to obtain random orientation of the crystals in wrought bars. This very greatly reduces the distortion of the uranium rods and it is now felt that this distortion will not be the limiting factor in the burnup achieved in graphite reactors of the Calder or CEA type.

At the higher temperatures which are likely to be characteristic of the fast reactor or sodium-graphite reactor the uranium is more plastic and we now encounter a different problem due to the pressure exerted by the fission gases. They appear to migrate to particular localities and to form high-pressure gas pockets which cause bulk swelling of the metal. If the metal is unrestrained the increase of volume may be as much as 40 per cent at 800°C. An immediate experimental answer to this form of distortion may be to provide a strong sheath. In this way the growth may perhaps be kept down to about 5 per cent. The full-scale fast reactor may well require a liquid fuel.

Another important problem is the effect of irradiation on mechanical strength and creep. At Geneva a Russian paper pointed out that under irradiation creep increased in some circumstances by a factor of the order of 1·5 to 1. Dr Cottrell has investigated this effect by irradiating loaded uranium springs in BEPO and he finds that during irradiation at 100°C the metal can creep slowly (0·1 per cent in a year) under stresses that are only about one-hundredth of the normal creep stress of the metal at that temperature. This could be important in particular reactor designs where the uranium was heavily stressed.

Similar problems arise, though not in such an acute form in the case of most metals used under strain in reactors. An obvious example is the possible effect of radiation on the breaking strength of the pressure drum containing the reactors.

The effect of radiation on solid moderators is another important problem. The most striking effect has been found in the irradiation of graphite. Graphite crystals grow in one direction and contract in another due to the formation of interstitial atoms by neutron impact.

The result is that bulk graphite grows by 0·05 per cent during a year in a flux of 10^{13} neutrons/sq.cm./sec at a temperature of 150°C. At the same time, there are striking changes in the physical properties such as thermal conductivity, which is reduced by a factor of 7 under such conditions. The effects depend strongly on temperature since at high temperatures the damage anneals out as it is produced.

Along with this so-called "Wigner growth," goes a storage of energy due to interstitial atoms. At a temperature of 100°C and an irradiation of 1 year at 10^{13} neutrons/sq.cm./sec the stored energy is 110 calories per gram; at 30°C it is 190 calories per gram. A large part of this energy can be released by heating the graphite above the irradiation temperature. The graphite specimen will then show a quite spectacular spontaneous heating.

We still have a great deal to learn about the storage mechanism and behaviour at high temperature — particularly about the reason why part of the stored energy does *not* cancel out.

4 Chemical Problems

One important group of problems is concerned with the compatibility of the materials used in reactors, particularly that of coolants with fuels, moderators and canning materials.

In gas-cooled graphite-moderated reactors the principal compatibility problem is that of CO_2 with graphite. The reaction could lead to the formation of carbon monoxide and to some mass transfer of carbon from one part of the reactor and its cooling circuit to another. The reaction rate increases with radiation and a loop has been operating for some time in BEPO to study the magnitude of the effect. The results have shown that at the graphite temperatures we may expect in Calder Hall, and in the future CEA reactors, the effects are not likely to be significant, but they might prove to be a limiting factor in raising the temperature of the reactor core well beyond 400°C. In order to make higher temperatures possible with CO_2

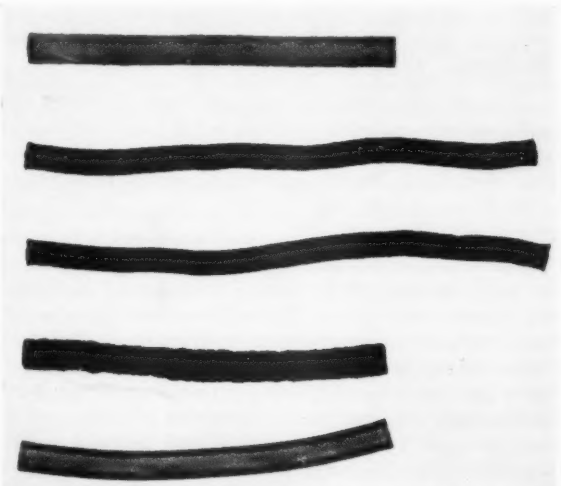


Fig. 3 ***the effect of 850 thermal cycles on a cast uranium bar. Reading from top to bottom: as cast, hot rolled, cold swaged, beta annealed, beta quenched***

as a coolant it would probably be necessary to find means of reducing the porosity of the graphite.

In water-moderated reactors the principal problem is the compatibility of hot water with uranium, for if a fuel element sheath develops a leak it must not be possible for a rapid attack of the fuel to take place. Experiment has shown that unalloyed uranium is attacked far too rapidly to be tolerated and if metal fuel elements are used it is necessary to resort to alloying to reduce the corrosion rate. This increases the neutron absorption markedly and a preferable alternative for civil reactors is to use sintered uranium oxide fuel elements, since they are very resistant to attacks by hot water.

The hot water must also be compatible with the fuel element sheath and to achieve this the US have developed Zircaloy—an alloy of zirconium. Research is proceeding at Harwell on a range of aluminium alloys which might withstand the conditions in water reactors. If successful, these would lead to a reduction in fuel element costs.

Compatibility must also be achieved with the pressure vessel and external circuit material. An obvious but expensive method is to use stainless steel throughout or at least for linings. However, this is difficult to decontaminate from fission products and is liable to stress corrosion. It may be possible, as a result of loop tests now proceeding and adequate control of water conditions, to use mild steel.

In sodium graphite reactors the hot sodium is compatible with uranium metal fuel, so one compatibility problem is removed. On the other hand the sodium must not be allowed to penetrate the pores of the graphite or too much reactivity would be lost. One possible solution is to can the graphite in hafnium-free zirconium.

Unfortunately, zirconium is a very good "getter" for oxygen and so will take up any oxygen leaking into the system. Oxide leads to embrittlement and so the oxygen content of the sodium must be kept below 10 parts per million. This difficulty may well force the designer to use a calandria design.

Compatibility problems are still more acute in the aqueous homogeneous reactor, for it has been found that the corrosion rate of the zirconium vessel holding the core fluid—uranyl sulphate—increases strongly with radiation intensity.

In solid fuel reactors, chemical problems arise from the need to recycle fuel if overall burnups of the order of 10,000-20,000 MWD/t are to be achieved in future nuclear power systems. The well-known aqueous solvent extraction processes are likely to be used and in large-scale plants are likely to achieve low separation costs—of the order of £1,000 per ton of uranium metal processsed. This has to be compared with an initial fuel element cost of £15,000-£20,000 per ton. The separated plutonium will now have to be refrabricated in closed boxes, because of its toxicity. Here is a good opening for automatic remote-controlled fabrication. We do not yet know the costs of refabrication under these conditions, but development work is proceeding to determine this.

Quite different chemical processing methods will be required for the breeder reactors. The fast breeder will possibly require a large number of recycles in the life of its expensive fuel owing to the severe radiation damage. Aqueous processing methods require the fuel to cool for 100 days or so to allow the radiation level to decrease. These two factors will probably lead to unacceptably high fuel investments and processing costs so that chemists are now working on pyrometallurgical processes—which essentially consist of melting the fuel elements, skimming off the waste products and reforming. This is likely to be a lengthy development job.

In thermal breeders such as the aqueous homogeneous reactor and the liquid-metal-fuelled reactor. continuous processing of the core is possible in principle and work has been proceeding on this for some time.

When the UK nuclear power stations reach an output of 20000 MW they will be producing about 6 tons a year of radioactive fission products. This is not a large volume—certainly it is small compared with the volume of ash from present UK power stations. We can, therefore, deal with the problem by evaporation and storage in large stainless-steel tanks of the type we now use at Windscale. Geneva papers, particularly from Hanford, showed that storage would contribute only one or two per cent to the cost of nuclear power.

The waste products do, however, contain radioactive isotopes, which are potentially valuable. Caesium 137 which emits a 600 keV gamma ray and has a half-life of 33 years is an important example.

The Windscale research laboratories are now separating caesium 137 on a pilot scale and the product is soon going to be used to provide kilocurie sources for radiotherapy in hospitals. Caesium might well in time replace 200 KV X rays for therapeutic treatment. Other potential applications are to industrial processes and here sources of the order of a million curies might be available by the 1960's.

The development of nuclear power requires an intensive programme of research and development continuing over at least the next two decades. At the present time the Atomic Energy Authority employs about 1000 qualified scientists and technologists—a little over two per cent of the total research and development staff of this country, and about one-tenth of the US effort. In view of the magnitude of the nuclear power programme and the fact that it is basic to our whole economy this does not seem to be an undue proportion of our resources.

The effort is now being supplemented by industry in the design of nuclear power stations and as the programme builds up, their share will increase. Given this additional effort, there is little doubt that nuclear power will make a substantial contribution to our energy resources by 1965 and that its contribution will grow rapidly in the second decade.

This article is based on Sir John's opening address on July 3 to a conference on the physics of nuclear reactors organised by the Institute of Physics in collaboration with the British Nuclear Energy Conference.

Protection of plant and personnel in the event of any fault condition is an essential part of reactor design

The safety of reactor control schemes

by J. Walker Control Group, Reactor Division, AERE, Harwell

THE DYNAMIC PERFORMANCE of a reactor control system may be analysed by the conventional servo-mechanism techniques, but before approaching the problem in this detail there is a wider aspect of reactor control which must be considered. In general only a small fraction of the controllable reactivity change is vested in the normal minute-to-minute control of the reactor, the larger part being associated with reactor safety under abnormal conditions. It is with this aspect that this paper primarily deals.

The philosophy outlined is drawn from world-wide experience in reactor technology, and some examples are quoted from British practice.

1. The reactivity worth of the control system

The total controllable reactivity change of a reactor should ideally be capable of keeping the reactor just critical under all conditions of inherent or uncontrolled reactivity change, plus a small margin to ensure that sufficiently speedy reduction in neutron flux can be achieved even under the most inherently reactive condition. When considering what the most reactive condition can be, account must be taken not only of the inherent reactivity changes resulting from reactor operation, such as temperature effects, fuel depletion, and fission product change, but also any foreseeable fault conditions which could conceivably arise. For example, accidental expulsion of liquid coolant from a system either by leakage or boiling, would, if this coolant were a significant neutron absorber, increase the reactivity as well as impair the heat removal. The removal of an experiment absorbing neutrons and its replacement by reflecting or moderating material would similarly lead to positive reactivity change. It is good practice to add a further safety margin to account for possible failure of individual units of the control element group and to permit safe maintenance of the control system.

The reactivity range of inherent effects will vary widely with the reactor type and its mode of operation. In reactors of modest maximum flux, say 10^{12} n/cm^2/sec, fission product poison build-up presents no problem, but may require a control investment of as high as 20 per cent in reactivity for a reactor working with a peak flux of 10^{14} n/cm^2/sec.

This method of assessing the control investment required is much idealized, and in fact it may be difficult to find sufficient space in the reactor to accommodate this amount of control. Indeed, it may be very bad neutron economy to do so. This apparent contradiction can only be resolved when the operational programme of the reactor is known, since continuity of operation and manoeuvreability from one power level to another are involved. If discontinuity is permissible, transient phenomena such as fission product poison build-up lose much of their importance, a small reactivity can be "built-in" to the reactor by using less fuel, and a small control investment accepted. This will however be unable to get the reactor out of the sub-critical region during the peak of the poison concentration transient. This state of affairs, known as "poison-out" would obviously be unacceptable in, for example, a military propulsion unit, where continuity of operation is a factor of paramount importance. In this case the built-in reactivity of the reactor must be made sufficiently large to over-ride the poisoning and the control investment sufficient to cope with the built-in reactivity. This over-ride is not the complete solution to the problem, for if the reactor is started up at peak poison concentration the destruction of Xe^{135} to Xe^{136} by increased neutron flux reduces the poisoning so rapidly as to give a reactivity addition rate which might be embarrassingly high. The xenon concentration thus represents a de-stabilizing influence on reactor control.

2. Control rates

There is no hard and fast rule which defines the maximum rate of reactivity addition or removal which should be possible, but it is generally accepted that a limit exists. This limit is dependent on the speed of operation of the safety devices and on the physical limitations of reactor components, particularly fuel elements, as to the maximum power or temperature conditions which they can support. It is naturally also dependent on the inherent reactivity changes, which may provide some form of automatic limitation to the addition rate which is possible. The general philosophy which the chosen control and tripping rates should satisfy is that power transients taking the reactor to dangerous temperature conditions must be subject to reliable trip action, and the energy input into the system during a power overshoot after tripping must be limited. The reliability of trip devices is involved, and the rates chosen will depend, for example on whether reactor period trips at low powers are accepted as sufficiently reliable, or whether it must be assumed that only excess flux trips can be made completely "fail-safe". It may

THE SAFETY SYSTEM of a nuclear reactor must be designed so that the maximum possible reactivity conceivable under any combination of fault conditions can be removed and the reactor brought sub-critical before any catastrophic situation is reached. This is generally achieved by the primary shut-off system backed by a secondary or safety system. A third independent system, controlled by some reactor variable such as fuel temperature is also recommended by the author. The form these controls should take is discussed and the system used in the DIDO reactor at Harwell is described.

The importance of power measurement down to the lowest levels is emphasised and factors affecting the design and location of ionization chambers and neutron counters are considered.

LE SYSTEME DE SÉCURITÉ d'un réacteur nucléaire doit être construit d'une manière permettant d'éloigner la réactivité maxima qu'on peut imaginer pour une combinaison quelconque des sources d'avarie ainsi que de ramener le réacteur à la condition sub-critique avant qu'une situation catastrophique soit atteinte. Ceci se fait en général au moyen d'un système primaire d'interruption, aidé par un système secondaire dit de sécurité. L'auteur récommande l'emploi d'un troisième système indépendant, reglé par une des variables du réacteur, p.ex. la température du combustible. On discute la forme des organes de réglage et l'on décrit le système employé dans le réacteur DIDO de Harwell.

On souligne l'importance de mesurer la puissance jusqu'aux niveaux les plus bas et l'on envisage les facteurs influant sur la construction et l'emplacement des chambres d'ionisation et des compteurs de neutrons.

DAS SICHERHEITSSYSTEM eines Kernreaktors muss so konstruiert werden, dass die denkbar grösstmögliche Reaktivität bei einer beliebigen Kombination von Fehlbetriebfaktoren weggeschafft und der Reaktor in den subkritischen Zustand übergeführt werden kann, bevor eine katastrophale Lage erreicht wird. Dies wird meistens mittels eines primären Ausschaltsystems bewerkstelligt, welches von einem sekundären (Sicherheits-)System unterstützt wird. Der Verfasser empfiehlt auch ein drittes unabhängiges System, das von einem Reaktorparameter, z.B. Brennstofftemperatur, gesteuert wird. Die Form einer derartigen Steuerung, sowie das im Harwellschen Reaktor DIDO angewandte System werden beschrieben.

Die Wichtigkeit der Leistungsmessung bis zu den niedrigsten Werten wird hervorgehoben, und es werden die für die Konstruktion und Aufstellung der Ionisationskammern und Neutronenzähler wichtigen Faktoren erörtert.

EL SISTEMA DE SEGURIDAD de un reactor nuclear debe diseñarse de forma que sea posible eliminar la máxima radioactividad que pueda concebirse en cualquier conjunto de condiciones defectuosas y hacer al reactor subcrítico antes de que se llegue a una situación catastrófica. Generalmente, ésto es conseguido mediante el sistema primario de cierre, respaldado por otro secundario o de seguridad. El autor recomienda también un tercer sistema independiente, controlado por alguna variable del reactor, como por ejemplo la temperatura del combustible. Es discutida la forma que deberían adoptar estos controles y se describe el sistema empleado en el reactor DIDO de Harwell.

Se subraya la importancia de medir la potencia hasta los niveles más bajos y son considerados los factores que afectan el diseño y emplazamiento de las cámaras de ionización y los contadores de neutrones.

СИСТЕМА БЕЗОПАСНОСТИ ядерного реактора должна быть так спроектирована, чтобы было возможно отвести максимальную мыслимую реактивность при любом сочетании аварийных условий и привести реактор обратно в подкритическое состояние, еще до достижения катастрофического положения. Это достигается обыкновенно посредством первичной системы выключения, которой помагает вторичная система (система безопасности). Автор рекомендует применять еще третью независимую систему, управляемую одной из переменных реактора, напр. температурой горючего. Обсуждается формаорганов управления и описывается система, применяемая в харуэллском реакторе DIDO.

Подчеркивается значение замера мощности вплоть до нижайшего уровня; обсуждаются факторы, влияющие на конструкцию и размещение ионизационных камер и счетчиков нейтронов.

even be decided to regard no man-made trip as completely adequate and to limit the rates of controlled reactivity addition to such as will be balanced by inherent changes such as temperature increase. This last approach implies very slow rates of addition indeed, because the thermal capacity of the reactor is usually large. For research reactors where temperatures are not unduly high, it is usual to rely on excess flux trips and these are therefore duplicated.

If the speed of operation of the safety control elements after trip is increased, greater reactivity addition rates before trip will be permissible, but actuations faster than provided by gravity require safety mechanisms of increased complexity and consequently higher probability of failure. In research reactors where gravity is used a rate of addition of about one per cent in reactivity per minute is frequently met, though, as with the selection of the total investment, each reactor must be considered on its own merits.

3. The sub-division of control elements

The control system of a reactor must not only make the reactor safe by making it subcritical under fault conditions, but also provide the operator with a means of manoeuvre from one flux level to another. Control elements are therefore basically segregated into these two functions, though it may be convenient to employ mechanisms which combine both features. It is current practice to further subdivide that part of the control system associated with safety, in order to increase its reliability and provide uninterrupted safety under certain special operational conditions.

The functions, already described, of being capable of making the reactor sub-critical in all foreseeable circumstances which might arise in the course of normal operation, forms the first subdivision and is known as the primary shut-off system. This is backed up by a secondary or safety system which provides spare reactivity control available if the reactor should diverge during a period when it should

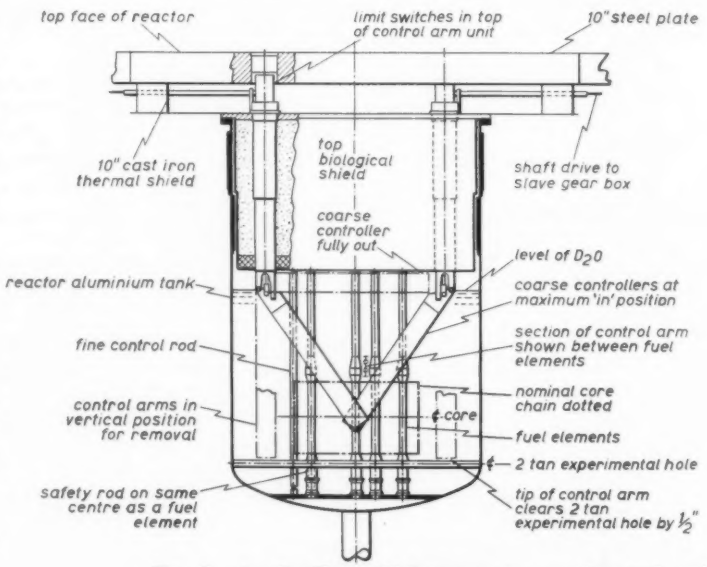

top face of reactor
limit switches in top of control arm unit
10" steel plate
10" cast iron thermal shield
top biological shield
shaft drive to slave gear box
coarse controller fully out
level of D_2O
reactor aluminium tank
coarse controllers at maximum 'in' position
fine control rod
section of control arm shown between fuel elements
nominal core chain dotted
control arms in vertical position for removal
℄ core
fuel elements
℄ 2 tan experimental hole
safety rod on same centre as a fuel element
tip of control arm clears 2 tan experimental hole by ½"

Fig. 1 ***in the Harwell heavy-water moderated and cooled research reactor DIDO, coarse control is provided by 'railway signal' type of control arms***

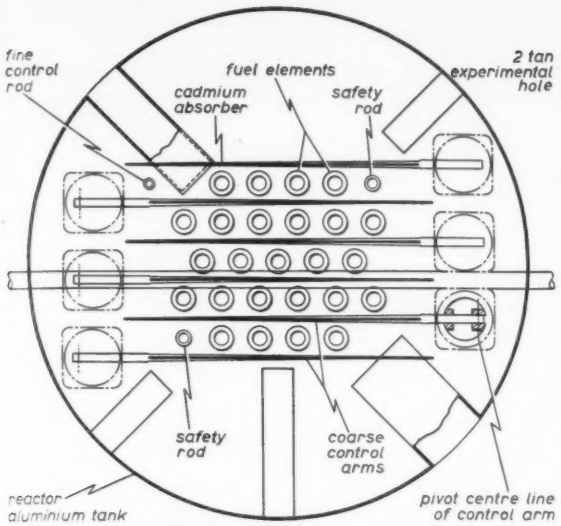


Fig. 2 ***DIDO has six coarse control arms, a single vertical rod for fine control and two vertical secondary safety rods***

normally be subcritical with the primary system exerting its full influence. This condition can arise when fuel loading changes are made, and this secondary system is provided because such changes are generally only slowly reversible in terms of the period which could be acquired by the reactor. Thirdly, it is desirable to include in the reactor a safety device entirely independent of the operator and the external trip circuits. Such a system could be operated by the change of some physical variable within the reactor, such as an excess temperature associated with the fuel, and would be non-self-resetting.

The basic safety need to limit reactivity addition rate implies both primary shut-off rods and secondary safety rods must have a controlled maximum speed throughout their travel. It may therefore be convenient to use the former as coarse control as well as shut-off devices in reactors where this form of control is wanted.

For the normal control of a reactor, either manu-

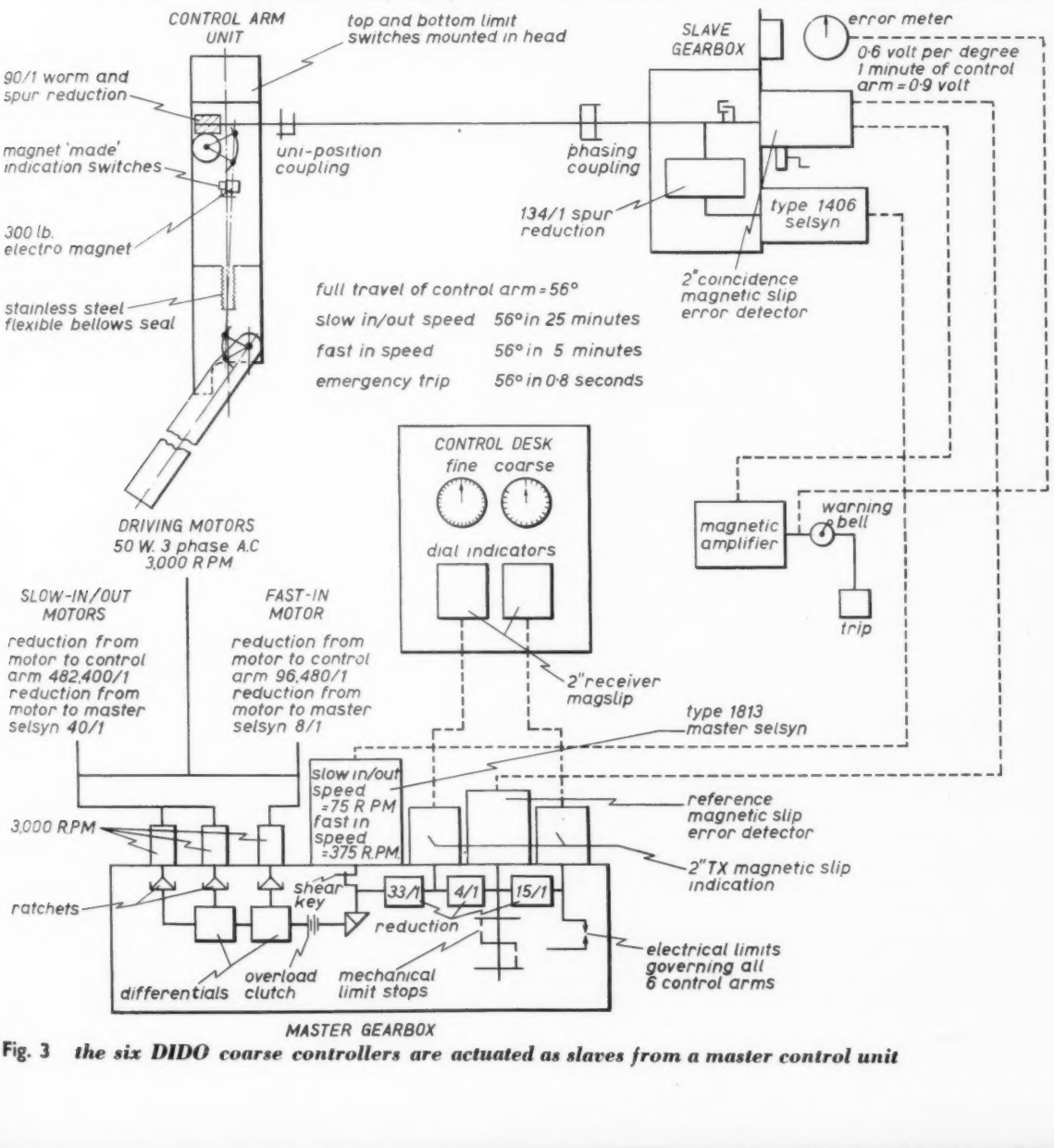


Fig. 3 ***the six DIDO coarse controllers are actuated as slaves from a master control unit***

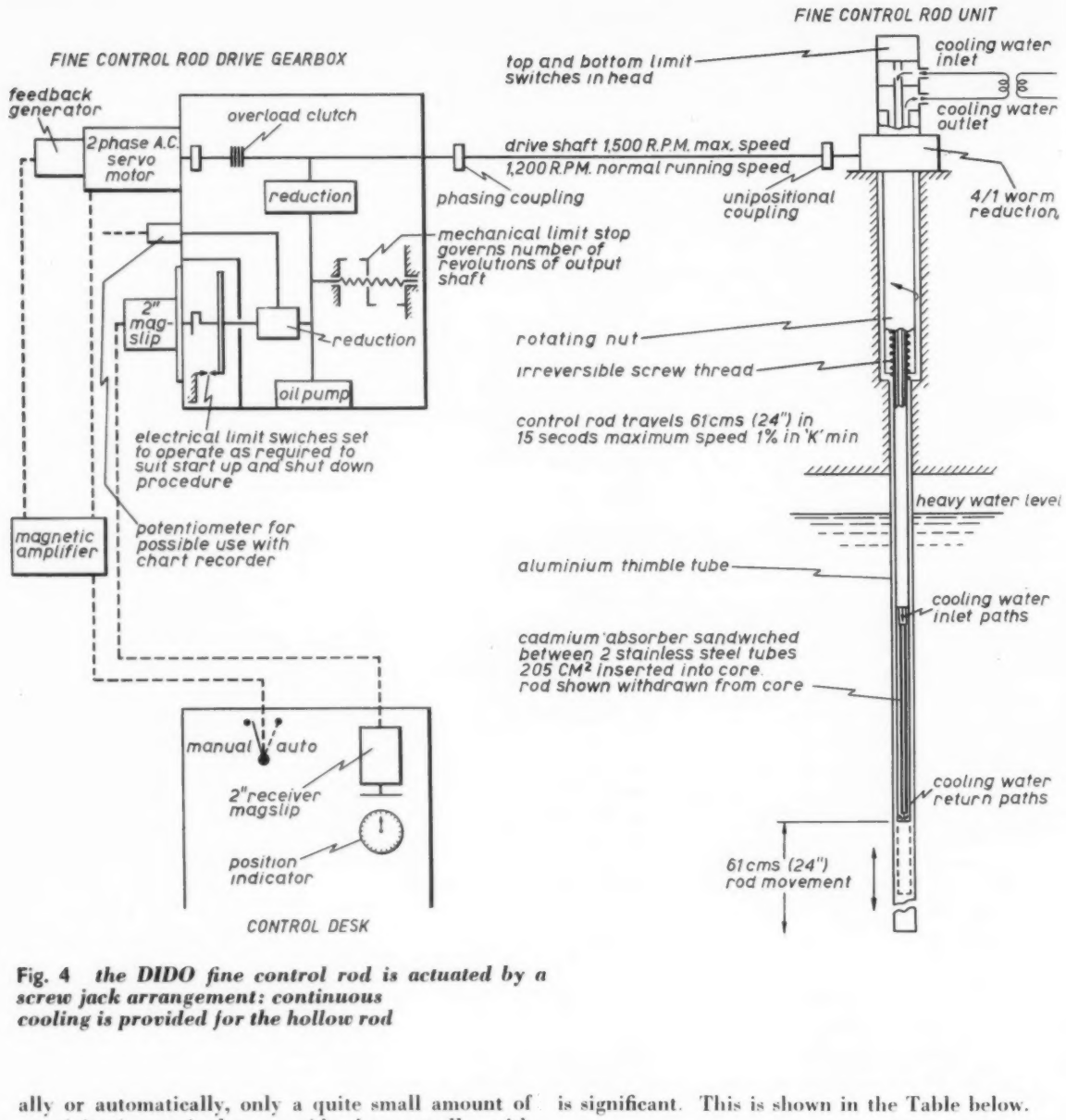

FINE CONTROL ROD UNIT
FINE CONTROL ROD DRIVE GEARBOX
top and bottom limit switches in head
cooling water inlet
cooling water outlet
feedback generator
overload clutch
2 phase A.C. servo motor
drive shaft 1,500 R.P.M. max. speed
1,200 R.P.M. normal running speed
reduction
phasing coupling
unipositional coupling
4/1 worm reduction
mechanical limit stop governs number of revolutions of output shaft
2" mag-slip
reduction
rotating nut
irreversible screw thread
oil pump
control rod travels 61cms (24") in 15 secods maximum speed 1% in 'K' min
electrical limit swiches set to operate as required to suit start up and shut down procedure
heavy water level
magnetic amplifier
potentiometer for possible use with chart recorder
aluminium thimble tube
cooling water inlet paths
cadmium absorber sandwiched between 2 stainless steel tubes 205 CM² inserted into core. rod shown withdrawn from core
manual
auto
2" receiver magslip
cooling water return paths
position indicator
61cms (24") rod movement
CONTROL DESK

Fig. 4 ***the DIDO fine control rod is actuated by a screw jack arrangement: continuous cooling is provided for the hollow rod***

ally or automatically, only a quite small amount of reactivity is required to provide the controller with as wide a range of reactor period as may ever be needed. It is undesirable that large amounts be available for this purpose, as mal-operation might lead to excessively short reactor periods and large power transients. The action of the controller may therefore be limited to a fine control system whose total reactivity worth is significantly less than the fraction of the delayed neutrons from fission. The primary shut-off system will certainly have a much greater investment than this, and if it is used for regulation it must be relatively insensitive in terms of travel per unit reactivity change.

The range of control investment met in the primary system may be demonstrated by comparing the research reactors GLEEP, BEPO, and DIDO, the last being a high-flux system where xenon poisoning is significant. This is shown in the Table below.

	GLEEP	BEPO	DIDO
built-in reactivity of core per cent	0·25	1·4	23·4
Primary shut-off system per cent	0·31	2·2	25

Movement of rigid absorbers or fuel elements is not always the most satisfactory method of exercising fine control. In homogenous reactors, for example, control can be achieved by varying the liquid fuel concentration.

4. Desirable features of control mechanism design

When a control system is designed there are certain features which should if possible be incorpora-

ted in the mechanism used in order to reduce the probability of complete failure of the system. For example, at least two types of mechanism should be used since it is not possible for any designer to postulate all the possible causes of mal-operation to which any one system may be liable. He would naturally design each system to be proof against all foreseeable faults. This is probably a weightier consideration in research reactors than in power-generating plants, because of the greater flexibility required, and while the existence of two types of mechanism may not be vital, it is certainly convenient in engineering the two different functions of the primary and secondary systems.

For similar reasons it is preferable that each type should comprise a number of units, rather than that the total reactivity be vested in a single device. As before, this may not be vital, but practically it eases the maintenance requirements.

Groups of elements covering one particular function should move in parallel together, the specified limit on reactivity rate being observed. With this arrangement, faulty connections cannot increase the maximum rate possible, which would be the case if sequential operation were permitted. Compressible fluids should be avoided as operating media since their use makes guarantee of a maximum rate difficult.

Wherever possible natural forces such as gravity should assist shut-down. This may not always be possible for mobile reactors, but for stationary ones the principle is universally applied.

As they are the "safety valves" of any reactor, the shut-down release features should be made as simple and reliable as possible, and it is general practice to arrange that internal faults in any member of a group of control elements actuate the release mechanisms of the whole group.

5. The design limitations of a practical system

When considering a practical control system for a research reactor, the designer is faced with the competing requirements of other reactor users, and ideal control systems whose detailed performance is completely predictable before the reactor is commissioned at very low power levels are rarely if ever achieved. The calculation of control absorption is exactly possible only for very simple geometries. In research reactors the trend is always towards higher fluxes and smaller reactor cores, with the maximum possible utilization of the volume of high flux in and around the core for experimental purposes. The space left to the control engineer is therefore limited.

This is well illustrated by the control system of the high flux, D_2O moderated, 10 MW thermal reactor, DIDO, now nearing completion at Harwell, and described at the Geneva Conference 1955.[1]

A general layout of the control system within the reactor structure is shown in Fig. 1. The control elements are six signal-arms forming the primary shut-off and coarse control, two secondary safety rods, and one fine control rod. An additional means of reducing the reactivity of the system is by dumping a sufficient volume of heavy water to remove the top reflector without impairing the fuel coolant system.

In this reactor the preferable geometry of control surfaces moving parallel to the axis of the core could not have given the large control investment required in the space available. An axially moving system oblique to the core might have made the control drive mechanism simpler, but was unacceptable because of the fact that two gas seals would have had to be penetrated, the high purity helium blanket for the heavy water, and the helium atmosphere of the outer graphite reflector. The only remaining alternative giving reasonable ease of removal for maintenance etc., is that chosen, a signal-arm type of element pivoted at one end and traversing an arc of some 56°. The calibration of the elements will be experimentally determined. For design purposes, as a first order approximation, it has been assumed that control will be directly proportional to absorbing surface area within the core, and the mechanism has been designed to give as nearly as possible a linear relationship between this and angular displacement. Special care has been required in the design to ensure that no overtravel beyond the most absorbing position is possible under normal operation, though it is unfortunately necessary to do this for maintenance removal. This has been reflected in the design of interlock circuits permitting only one arm to be so dealt with at one time, and fuel may have to be removed before carrying out this operation because of the large reactivity investment of each control arm. Space is restricted not only within the core, but in the surrounding working spaces within the reactor building including the control room, and rather than control the six coarse control arms by six independent servo-mechanisms, it has been found more convenient to actuate all six as slaves from a single master unit, from which position indication is taken. This has required the development of a unit monitoring quite small misalignment between any of the slaves and the master. Fig. 2 shows a plan view of the layout of the arms, and Fig. 3 a schematic diagram of the drive system.

The safety rods, controlling only 3 per cent in reactivity, are outside the reactor core, and are much more conventional in design. The fine control rod, also of conventional axial travel, is complicated by the need for continuous cooling during operation. Fig. 4 shows the design used to achieve this.

to be continued

In the article on zone melting by J. E. Antill in last month's issue, there was an error in the caption to Fig. 3—in the second line the word should be "decontamination". In Fig. 7 it was not made clear that the upper photomicrograph was of a natural uranium bar before zone melting while the lower one showed conditions at the top of the bar after zone melting.

Scotland's share in nuclear energy *by a special correspondent*

Would a separate AEA help ?

SCOTLAND HAS been interested traditionally in heavy engineering activity, to an extent which resulted in the loss of the newer assembly and light fabrication industries that emerged in the post-1918 period. This situation has now been redressed to some extent, although automobile and aircraft engineering appear to have been largely lost to the English Midlands. The advent of atomic power raises a number of obvious questions of particular interest to Scottish industry. Can Scotland claim a full share of the work involved in this new field? What progress has, in fact, been made in this industry? What are the forward prospects?

These questions can be answered simply and with relative ease. By and large, considerably by the work made available Scottish industry has already benefited by the atomic energy programme, both insofar as fabrication and civil engineering are concerned. What is now needed is a steady flow into Scotland of contracts both on the mechanical and civil engineering sides of the programmes, and so far the indications are that the work is available for the firms which wish to share in it.

It might also be suggested that considerable progress has been made technically, insofar as accumulation of experience is concerned.

On the third point—it is a fair assumption that the prospects will continue to be favourable provided that leaders in the relevant industries continue to demand and secure an adequate share of the work involved; and that in turn will depend on the energy with which they pursue the training and cultivation of personnel competent to handle such work.

On this last point it is worth noting that the courses offered by the Royal Technical College (and by other Scottish bodies) on nuclear engineering have been very fully subscribed to by Scottish industrialists. What is particularly encouraging is the fact that many of the larger firms are sending senior executives to ensure that top management is informed on the scope, the conditions, the needs and the work which will be involved in this field.

The Scottish Council (Development and Industry) has taken a leading part in the encouragement of interest in this field and prepared some time ago a summary of some 80 firms concerned to take part in this developing field; all were established concerns in their own field, producing general output as well as specialised equipment of a type involved in the new programme.

Scotland is already represented in this connection and has a number of firms already actively engaged on atomic energy work both on fabrication and on civil engineering. Babcock and Wilcox Ltd are an example of such a unit while Whatlings Ltd are actively engaged on the civil engineering contract at Dounreay. There are many other firms with interests in this work and The Motherwell Bridge and Engineering Co Ltd, John Brown and Co Ltd, George Scott Ltd and Henry Balfour and Co Ltd of Leven, Alexander Findlay and Co Ltd of Motherwell, Barr and Stroud Ltd of Anniesland, G. and J. Weir Ltd of Cathcart, are among the firms whose interest has already been indicated and whose normal work makes them particularly suitable and competent to handle this newer work. There has been a very considerable number of sub-contractors involved already, handling valves, pipework, plating and metal-finishing, providing instruments and other accessories—making it clear that the activity is extending steadily and that many more firms than the original 80 prospects are sharing in the work.

There are admitted problems and limitations. One aspect which has been stressed is that all the research and planning work has so far been done in England. This has prevented the creation and development in Scotland of design teams in atomic engineering. It has also attracted from Scotland, men who could usefully have been retained in their own firms for the same type of work, had that been possible through the location in Scotland of an official planning and development headquarters.

Because of the need to ensure that such experience is gained in the early stages of development, the Scottish Council has welcomed the location in Scotland of atomic energy stations over the period of early activity, on the grounds that engineering concerns here can grow up with the new industry, meet the problems inherent in its economic and technical mastery, and gain the invaluable experience which only such a process permits. It has been urged by some interests for instance that there should be a Scottish Division of the Atomic Energy Authority; the selfish reasons are the difficulties which certain firms have experienced in making the right contacts from a distance 400 miles from the centre of research and development activity; the broader argument is that lack of such a Division handicaps Scotland in the race for a share in world markets which will accrue over the next 50 years. The Scottish Council (Development and Industry) view is that 'if the generating stations can be brought here, and if adequate liaison is maintained between firms and the Electricity Authorities, and if firms take adequate steps to recruit properly trained men, then the work will flow naturally to Scottish industry.' When the Scottish Council made an approach to the Authority with regard to placing of contracts in Scotland they met with a satisfactory response in a share of perhaps 10 per cent of the initial contract. There was no resistance to the placing of such work in Scotland but rather a lack of appreciation that Scottish firms could undertake the contracts. That situation has been corrected in the later work at Dounreay and Annan, on which Scottish firms are to be very fully employed. But that still leaves unsolved—some others contend—the need for a central authority in Scotland to coordinate research, design and technique, to advise and assist experienced and suitable firms to undertake the newer work, and to campaign for the development in Scotland of a nuclear engineering industry as such.

There are further implications in terms of loss of younger scientists and technicians. The Scottish universities and colleges have been feeding graduates to England and abroad for years largely because of the lack of suitable research appointments in Scotland. That situation has been corrected in the sphere of hydro-electricity and electronics by the creation of sturdy growing industries encouraged by the fact of local activity. Hydro-electricity in particular has given an immense amount of work to local firms as well as to national concerns and has been the means of keeping many Scottish firms alive and growing. The need is for a similar situation in atomic engineering, and that might mean the location within Scotland of a Division of the Authority. If undue emphasis has been placed on this aspect of the current activity it is justified by the necessity for action within the near future to ensure that Scottish engineering is fully informed of all the developments, and is to acquire the 'know how' to play its full share.

Heat recovery from reactors

For steam raising, nuclear heat can be used alone or in combination with fuel heat. This leads to several possible arrangements, the relative merits of which are discussed by P. Chambadal and J. P. Roux of Électricité de France

FOR REACTOR STABILITY, the heat released must be removed continuously by means of circulating fluid which, according to its nature and pressure, can be used in either an open or closed circuit.

Among the factors which influence the transformation of a given quantity of heat into work one of the most important is the temperature at which it is available. This not only determines the energy available from the hot fluid; it also influences the choice of fluid.

The expression for the available energy in a working substance can be shown to be:

$$W = H_1 - H_2 - T_2(S_2 - S_1)$$

H_1 and H_2 being the initial and final enthalpies of the fluid and S_1 and S_2 the corresponding entropies. The initial temperature T_1 determines H_1 and S_1 so that W depends on T_1.

This expression is, of course, applicable only to ideal cycles: under real conditions, the choice of working fluid can influence the work done. When the initial temperature T_1 is sufficiently high the working fluid may be a vapour or a permanent gas (*i.e.*, one which does not condense during any part of the cycle): if it is relatively low, however, the latter must be ruled out. For example, steam turbines have worked for many years at inlet temperatures of 200-300°C; a gas turbine under these conditions would have a negative efficiency. At the moment, reactor coolant temperatures are still too low to allow heat recovery in a gas turbine: this can only be done using steam. This alone, however, is insufficient to define the exact method, for such an installation can be realised in several different ways.

These fall into two classes:—

1. there may or may not be an additional external source of heat.

2. the heat can be supplied to water or steam.

Four possibilities are therefore open, shown diagrammatically in Fig. 1. It will be shown that the choice between them is partly determined by a peculiarity of nuclear energy: because the heat source is strongly radioactive, the recovery system must satisfy not only the normal considerations of efficiency, economics etc. but must be designed to reduce maintenance to the absolute minimum—so far as the radioactive part of the plant is concerned.

1. Steam direct from nuclear heat

Suppose the reactor coolant is a gas which, on leaving the reactor is taken through a steam generator (waste heat boiler). This comprises feed heater, evaporator and possibly a superheater, but to simplify matters, let us ignore the latter and assume that the steam is merely dry and saturated. Furthermore, let us ignore the drop of temperature required for heat transmission. Finally, assume that expansion takes place in a perfect turbine. Under these ideal conditions and for a given condenser outlet temperature (*e.g.* $t_2 = 30°C$) the efficiency of the recovery—the ratio of work done to heat supplied — depends only on the initial temperature of the gas t and of steam temperature Θ (*i.e.*, saturation temperature). The variation of these two parameters is shown in Fig. 2. It can be seen that for moderate values of t the curves $\eta_i = f(\Theta)$ are vertical parabolae, the maxima defining the optimum value of Θ corresponding to the given temperature t. But the curves $t = 400°$ and 450°C show to the right of the maximum, a minimum after which they rise to a limit corresponding to the critical temperature of water (374°C). For $t = 500°$ and 550°C the maxima and minima disappear but the curves have points of inflection. Finally, for $t = 600°$ and 650°C the maximum reappears. For this last curve, all the available heat is transmitted to the water so that η_i becomes the same as the maximum efficiency of the saturated steam cycle: this corresponding to $\Theta = 350°C$, is 40·6 per cent.

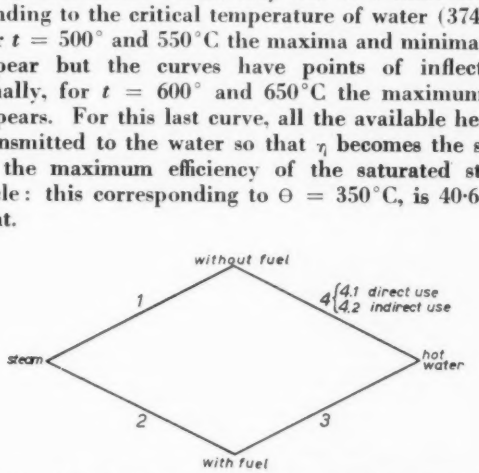


Fig. 1 ***in a heat recovery system, heat may be applied to steam or to water: it can also come only from a reactor or be supplemented from conventional fuel***

This allows us to find for every value of t the optimum value of Θ and the maximum value of η_i (Fig. 3). The variation of Θ_{opt} as a function of t is shown by a sloping straight line and two horizontal lines. The variation of $\eta_{i\,max}$ with t is represented by two curves intersecting at a point where $t = 405°C$. This corresponds sensibly to the limit of available temperatures at the exit from a reactor; the region in which we are interested lies to the left of this point. Here approximately

$$\Theta_{opt} = 16 + 0{\cdot}475\,t$$

and $\eta_{i\,max} \quad 0{\cdot}006\,t$

The dashed line gives the values of η_e which would obtain if all the available energy in the hot gas trans-

HEAT FROM A NUCLEAR REACTOR may be used to raise steam either alone on in combination with an external source of fuel heat. In addition, the heat can be supplied either to water or to the steam. Thus, four possible methods of steam raising are possible. A very promising method is that of using nuclear heat only for feed water heating, with a conventionally fired boiler supplying evaporation and superheat. It is shown that this is thermodynamically equivalent to continuous feed heating by bled steam. Another method is by using flash steam boilers in cascade. A description of the power plants of the French G1, G2 and G3 reactors at Marcoule is included.

ON PEUT UTILISER LA CHALEUR des réacteurs nucléaires pour la génération de vapeur sans ou avec une source extérieure de chaleur dérivée d'un combustible. En plus, cette chaleur peut être délivrée à l'eau ou à la vapeur. Donc il existe quatre possibles méthodes de génération de vapeur. La méthode qui parait promettre de meilleurs résultats est celle où l'on utilise la chaleur nucléaire seulement pour chauffer l'eau d'alimentation, tandis que l'évaporation et le surchauffage se font dans une chaudière normale. On montre que, du point de vue de thermodynamique, ce système est équivalent à celui où l'eau d'alimentation est chauffée d'une manière continue par vapeur épuisée. Une autre méthode est celle employant des bouilleurs en cascade. On décrit les centrales électriques des réacteurs G1, G2 et G3 de Marcoule (France).

KERNREAKTORWÄRME KANN ENTWEDER allein oder zusammen mit einer äusseren Brennstoffwärmequelle zur Dampferzeugung angewandt werden. Ausserdem kann die Wärme entweder dem Wasser oder dem Dampf zugeführt werden. Es gibt somit vier mögliche Dampferzeugungsmethoden. Ein sehr aussichtsreiches Verfahren besteht darin, dass Kernwärme nur zur Speisewasservorwärmung benutzt wird, wobei Verdampfung und Überhitzung in einem üblichen Dampfkessel erfolgen. Es wird gezeigt, dass dieses Verfahren thermodynamisch der kontinuierlichen Speisewasservorwärmung mit Abdampf gleichwertig ist. In einer anderen Methode werden "Flash"-Dampfkessel in Kaskaden angewandt. Zum Schluss werden die Kraftanlagen der französischen Reaktoren G1, G2 und G3 in Marcoule beschrieben.

EL CALOR DE UN REACTOR NUCLEAR puede utilizarse para generar vapor, bien por sí solo o en combinación con una fuente exterior de calor de combustible. Además, el calor puede aplicarse al agua o al vapor. Por lo tanto, existen cuatro métodos posibles de generar vapor. Uno de ellos, muy prometedor, consiste en usar calor nuclear únicamente para caldear el agua de alimentación, con una caldera de atizaje corriente proveyendo evaporación y supercalor. Se demuestra que ésto es equivalente termodinámicamente a un continuo caldeo preliminar por vapor de derivación. Otro método es mediante el uso de calderas de vaporización instantánea en cascada. Es incluida una descripción de las plantas generadoras de los reactores franceses G1, G2 y G3 de Marcoule.

ТЕПЛО, ПОЛУЧАЕМОЕ из ядерного реактора, может использоваться для парогенерации или как единственный источник тепла или в сочетании с другим, наружным источником тепла из обычного топлива. Кроме того тепло может поглощаться водой или паром. Следовательно существуют четыре возможных метода парообразования. Подающий большие надежды метод состоит в том, что ядерное тепло употребляется лишь для подогрева питающей воды, в то время как парообразование и перегрев происходят в котле с обычной топкой. Доказывается, что в термодинамическом отношении этот метод равноценен методу непрерывного подогрева питающей воды отработанным паром. В другом описанном методе применяются каскады «вспышечных» паровых котлов. Описываются также силовые станции французских реакторов G1, G2, *и* G3 *в Маркуль.*

This article is based on paper 99 J/2 presented to the 5th World Power Conference in Vienna. *M. Chambadal is Chief of Thermal Research in the Directorate of Electrical Studies and Research : M. Roux is Deputy Director of Nuclear Plant.*

formed into electricity; in other words, it shows for every value of t the ratio of usable energy to the total heat in the gas. It can be seen that although we have stipulated ideal conditions, the efficiencies obtained are distinctly lower than their theoretical limit.

It is possible, however, to improve them. In the coolant line from the reactor several heat exchangers might be placed in series supplying steam at different pressures. For a given gas temperature and a given number of heat exchangers, the optimum values of these pressures could be found and it is easy to show that the total efficiency is dependent on the number of stages.

Although there is a given flow at a given initial temperature in the usual waste-heat recovery plant in a reactor, it is not the *mass* flow but the *heat* flow which is settled in advance. To remove a given quantity of heat we can either have a high mass flow with a small amount of temperature rise or *vice versa*. From a thermodynamic point of view the first solution is preferable but a high mass flow means an increase in pumping power and this is permissible only when the fluid is a liquid because the power required is then only a small fraction of the total output. A water cooled reactor; for example, can have a high mass flow of coolant and the heat can be recovered in a single heater.

It is otherwise when the coolant is a gas because the blowers absorb a considerable fraction of the total output. The power can be reduced by cutting down the mass flow, but to maintain the same heat removal the inlet temperature would have to be lowered somehow. This would lead to a reduction in outlet temperature and hence of steam pressure and gross output. Reduction of gas flow has, therefore, two contrary effects on the net power output so that for any given case there exists an optimum value. To increase the net power several heat exchangers must be used in series and the optimum gas flow varies with their number.

2. Steam from reactor and combustion heat

Heat supplied by fuel combustion can be used to add heat to the reactor coolant. If the coolant is water, however, the process can only have limited applications, for the temperature cannot exceed the critical value of 374°C. On the other hand if the coolant is a gas its reheating requires a large amount of surface which complicates the installation. In these two cases the use of a conventional fuel would seem to be ruled out.

It is possible, however, to transmit the combustion heat to the working fluid direct so as to superheat it. This will use very much less fuel and provide a high efficiency but the superheater does involve a complication.

3. Nuclear heat for feed water heating

Nuclear heat can be used not to produce steam but for feed water heating. As the temperature of the coolant leaving the reactor is only moderate, this can be done without involving too big a temperature drop between the heating and heated fluids. The fuel heat

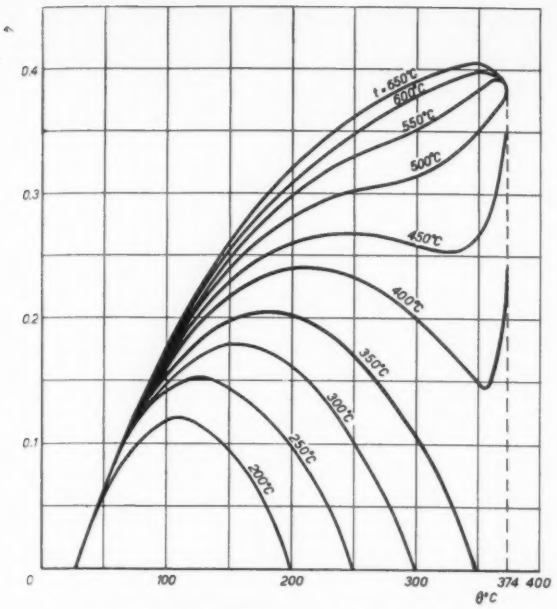


Fig. 2 *ideal efficiency (η_i) of the saturated steam cycle depends on gas temperature t and on steam temperature* Θ

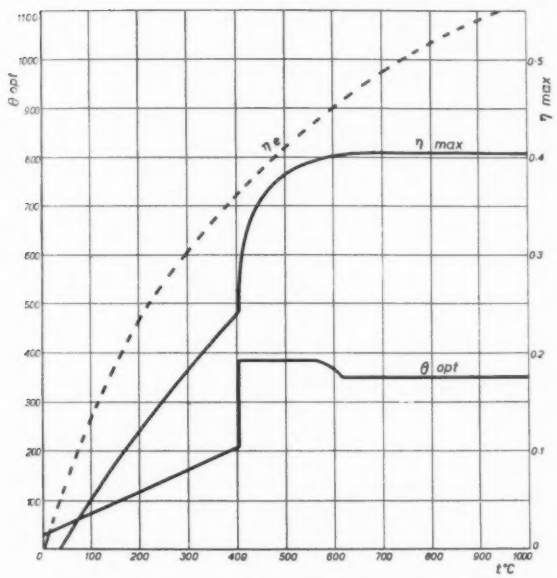


Fig. 3 *cross-plotting from Fig. 2 leads to a representation of the maximum attainable efficiency and optimum steam temperature*

can be used for evaporation and superheating; the nuclear heat only for sensible heat.

At first sight this process does not appear very interesting because it would seem to deprive the installation of the benefits of bled steam feed heating from the turbine. Let us examine the temperature/entropy diagram of an ideal steam turbine working without bleeding (Fig. 4). The area A B C D E represents the work done by one kg of steam and the area A′ A B C D D′ the corresponding heat used. The ratio of these two areas defines the cycle efficiency.

If the turbine is fitted with continuous steam bleeding for heating condensate from temperature T_2 to temperature T_1, the cycle will be practically equivalent to the circuit F B C D E and its efficiency will be very nearly the ratio of the areas F B C D E to B′ B C D D′. By substituting nuclear feed-heating a cycle is obtained where the work done by one kg of vapour is given by the area A B C D E (as in the cycle without continuous bleeding) while the heat supplied by the fuel is given by the area B′ B C D D′ (as in the bled steam cycle). This new cycle compared with a bled cycle supplies extra work represented by the area A B F, and this represents exactly the energy obtainable from one kg of water at temperature T_1. Thus the turbine will not only perform as if it had continuous bleeding but will provide extra work equal to all the available energy in the hot water supplied by nuclear heat.

Fig. 5 shows the layout of an installation of this kind. The reactor at 6 comprises a double shell 5 through which circulates the coolant. This passes through an exchanger 4 in which it gives up its heat to the feed water which then passes through a conventionally-fuelled boiler where it is turned into steam for the turbine 1. After leaving the condenser 2 it passes through a feed pump 3 and so back to the feed heater 4. A similar installation could be arranged comprising additional bled steam heaters placed up and downstream of the nuclear heat exchanger. The downstream one supplies the additional heat when the temperature of the reactor coolant is not sufficiently high, while the upstream one can be used when the temperature of the coolant must not be allowed to fall below a certain value.

4. Flash steam boilers

As in the previous case the heat in the reactor coolant is transmitted to water which remains in the liquid state, but this time the water receives only a part of the heat coming from outside. Transmission of heat always demands a certain temperature drop, so that the heated water is necessarily at a slightly lower temperature than that of the coolant coming from the reactor. This drop, however, is the only one that we have in this scheme and its two variants.

The first of these (4.1) corresponds to the direct use of hot water for the production of work. It consists in flashing hot water into steam actually inside a turbine during the expansion to condense vacuum. Theoretically there is nothing against this—under ideal conditions it would allow the recovery of all the available energy in the water—but, so far, attempts to build such a turbine have failed owing to the difficulty of keeping the temperature and pressure of the steam/water mixture at the saturation values in all the stages.

It is, however, possible to recover the heat from the hot water in a simpler manner. This (4.2) consists in expanding in a turbine, not all the available hot water, but a small fraction of it previously transformed into steam at the expense of the heat in the water remaining liquid. The water reheated by the coolant from the reactor leaves the heat exchanger

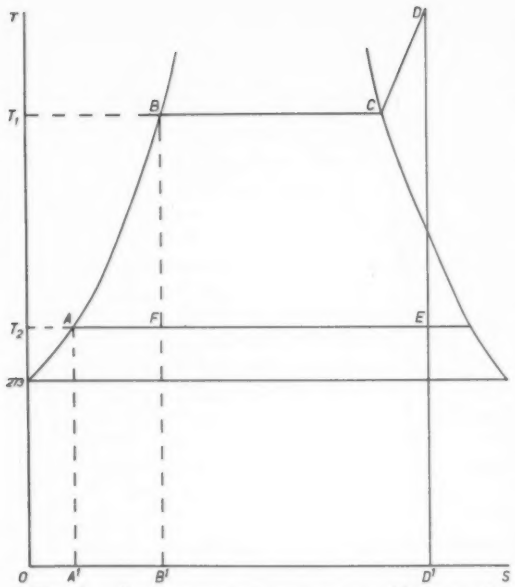


Fig. 4 ***the temperature-entropy diagram for the superheated steam cycle***

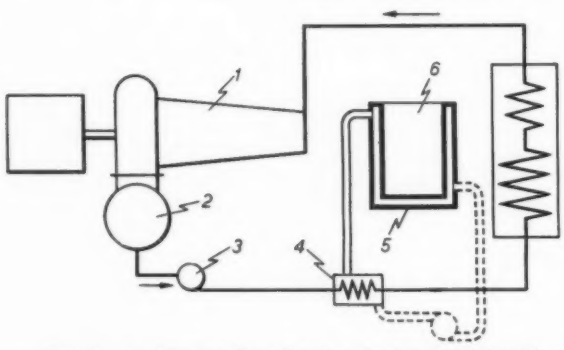
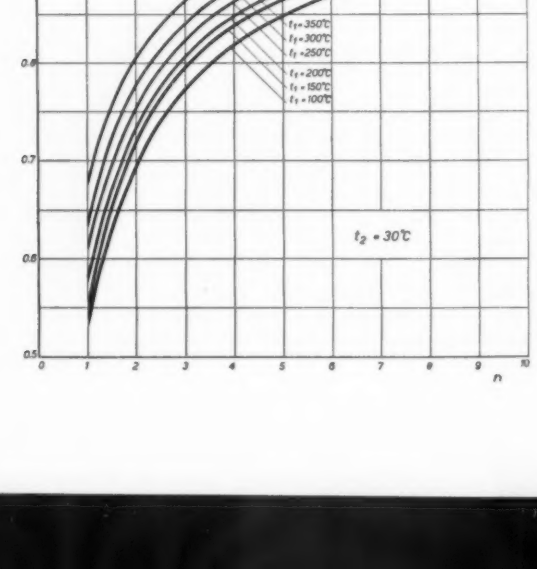


Fig. 5 ***using nuclear heat only for feed heating with fuel heat for evaporation and superheat (in the boiler on the right) leads to a cycle thermodynamically equivalent to one with continuous bled-steam feed heating***



at a pressure at least equal to the boiling point of the liquid at the corresponding temperature. It is necessary only to pass this water through a flash boiler to obtain a simultaneous lowering of the temperature and pressure. This releases heat which effects a partial evaporation of the liquid and the steam thus produced can be expanded in a turbine. For given values of initial and final temperatures the work done by the expansion per kg of hot water varies with the saturation temperature; when this drops, the weight of water evaporated rises while the available heat drop between this temperature and that of the condenser is reduced. It can easily be shown that as the saturation temperature varies, the work done passes through a maximum.

It is evident that the water coming from the flash boiler still contains heat which can be recovered in a similar way in another boiler. In fact, by using several boilers in cascade it can be shown that the optimum temperature of the first varies in the same sense as the number of boilers. As this tends to infinity, the optimum temperature of the first boiler approaches the initial temperature of the hot water, that of the last to the temperature of the condenser and the work done (under ideal conditions) to the available energy in the hot water. The influence of the number of boilers on the work recovered is shown in Fig. 6 where the coordinates n and ρ represent the number of boilers and the ratio of work done to available energy. It can be seen that the influence of number is higher for lower initial temperatures, but when this is equal to the critical temperature the water becomes transformed into steam in a single boiler so that no more are necessary. This can be seen from Fig. 7 which shows for different numbers of flash boilers the theoretical work done by a kg of water as a function of its initial temperature, the final temperature in each case being 30°C. It can be seen that all the curves n=constant intersect at $t_1 = t_2 =$ 30°C and for $t_1 = t_c = 374$°C (t_c being the critical temperature of water).

If we compare this solution with solution 3 we can see that in the temperature range of interest for a given number of stages (*i.e.* heaters or flash boilers) they are thermodynamically very nearly equivalent. The choice between the two solutions must then be guided by considerations other than thermodynamic. These affect the steam raising apparatus alone; the turbine is the same in both cases. Compared with solution 3, 4.2 presents several practical advantages. 1. In the two cases, the hot source of the cycle consists of reactor coolant—which is necessarily active; consequently the primary heat exchanger must be as simple as possible to reduce repair and maintenance to a minimum. Now in solution 4.2 this component is particularly simple; there is only one of them and it merely exchanges heat between water and water. On the other hand, in solution 3 it consists of one or many heaters, each one involving a feed heater, a tubular evaporator and finally a superheater.

Fig. 6 ***the ratio of work done to available energy (ρ) as a function of number of flash boilers (n) for varying reactor outlet temperatures***

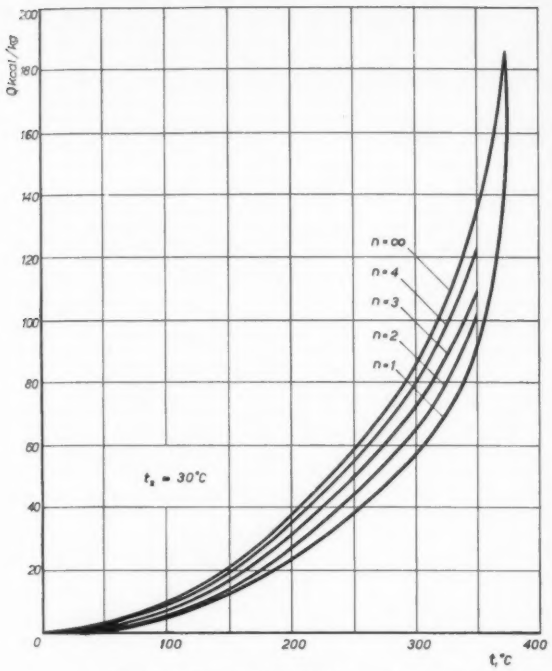


Fig. 7 ***the theoretical work done per kg of water as a function of initial temperature for various numbers of flash boilers***

2. Because the water passing through the exchanger remains in the liquid state (evaporation taking place in external boilers) scaling troubles are reduced. Scale deposits, practically inevitable in an ordinary boiler, could mean a risk of corrosion, a reduction of heat transmission, and frequent cleanings.
3. The flash boilers can be placed very close to the turbine and this reduces the length of steam mains and the corresponding pressure drop. This is particularly important because the volume flow of steam is, because of the moderate pressure, very high.
4. The connection between the heat exchanger and the turbine hall is simply two small pipes: consequently, if necessary, the turbine hall can be some way from the reactor.

Nevertheless, in certain circumstances the application of this process could be difficult. For example, when the pressure of the working fluid in the exchanger must for some reason be kept below a certain value the pressure in the first flash boiler, being necessarily lower than that of the liquid water, it might not be enough to allow sufficient recovery of the disposable heat. Here, it would be preferable to place in the hot fluid circuit one or two generators producing steam at relatively high pressure and combining them with one or several flash boilers supplying steam at lower pressures. This would improve the efficiency of the installation and also facilitate the use of turbine-driven auxiliaries.

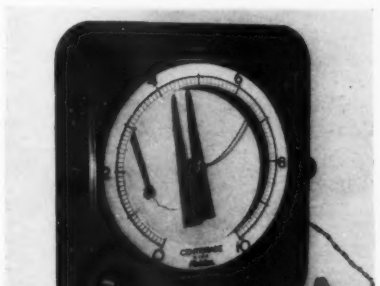
French plans for the building of nuclear power stations have been inspired by these considerations. They have for their aim the recovery of heat from the reactors G_1, G_2 and G_3 now under construction at Marcoule (Gard).

to be continued

EQUIPMENT

High performance, low maintenance industrial thermograph

The Pyro-Servograph by Fielden Electronics, Paston Road, Manchester 22, is a temperature recorder which operates in conjunction with thermocouples and it can be supplied for use with either base-metal or precious metal thermocouples, in various ranges from 0–300°C upwards. The instrument has been designed for industrial use and the motor-driven pen is positioned by an electrical servo system from a high-grade electrical meter. Automatic cold junction compensation is provided and the equipment has an accuracy of plus or minus 1 per cent. It is claimed, therefore, to be suitable for use in many of the applications which would otherwise necessitate a DC potentiometer, for although the accuracy is not as high as that obtained with potentiometric equipment it is adequate for the majority of industrial applications.



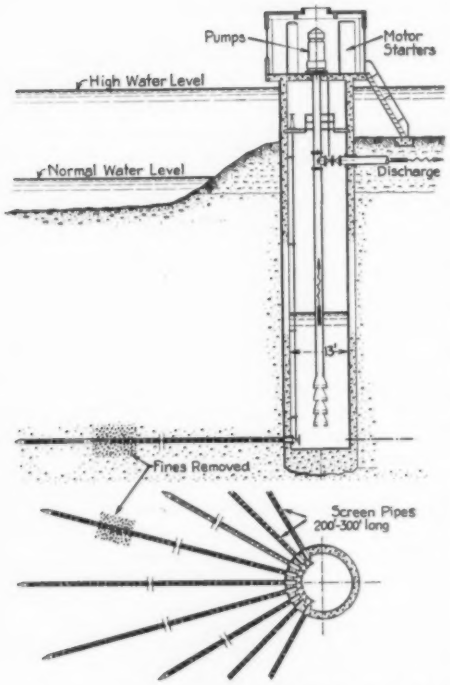
Fielden Pyro-Servograph available in various ranges

This recorder has been designed by Fielden Electronics Ltd. to give long trouble-free service and the mechanism has been kept as simple as possible. Gearing and moving mechanical parts have been cut down to a minimum and the simple electronic chassis itself is an interchangeable unit. The motor which drives the pen has ample power in reserve for operating alarm or control mechanisms and for driving the large central indicator both of which facilities can be provided at a small extra cost.

This instrument has had extensive field tests, has been evaluated in the plants of the major chemical, steel and petroleum undertakings, and has been praised for its high performance with low maintenance cost.

EQUIPMENT

Ranney water system for French A-plant



Induced filtration from river or lake brings water to concrete well

Nuclear power stations have a greater degree of freedom in respect of siting than coal or oil-fired stations since fuel transport is a minor consideration. Nevertheless, they are equally dependent on an adequate supply of water, both for condenser cooling and for feed water make-up. This can come from the sea, surface water or underground water, appropriate treatment being applied before it is used.

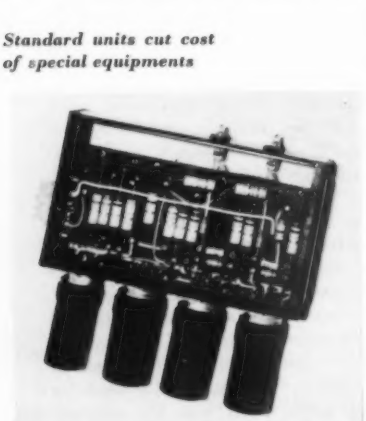
A system of obtaining underground or percolated surface water known as the Ranney Method has been in use in the United States for some years. In addition to many overseas associated companies, there is now a branch in the United Kingdom—Ranney Water Methods Ltd, 12 Queen Anne St, London W.1—who are also agents for the British Commonwealth. The basis of the method is the sinking of a vertical reinforced concrete shaft or caisson from the base of which radiate in a horizontal plane a number of perforated steel pipes. These pipes are in 8 ft sections and are pushed out into the water-bearing stratum by hydraulic jacks, sections being added by welding. These pipes can extend out to as much as 300 ft radius. The water percolating from the collector pipes collects in the bottom of the shaft from whence it is supplied to the surface by submersible borehole pumps. In the case of water obtained from a river, 24 in dia. filtration galleries may be used and these have been driven a distance of 450 ft. Provided the strata are suitable, fine sand and silt are first removed through the perforated pipes which gradually become surrounded by a sleeve of coarse gravels. From then on, the water is perfectly clear since the velocities are very low, the discharge being obtained from the very large area of pipe. Among the advantages claimed for the system is the fact that river water is effectively filtered in the actual collecting process, and with underground water, the temperature might be up to 20°C below that of surface water, an important consideration in heat exchanging applications. All sites undergo a thorough hydrogeological survey by the firm's engineers before it is decided to go ahead with construction.

These units can be made in very large sizes—in America installations exist providing up to 20m gallons a day from a single unit. The Wabash River Ordnance Works, where one of the Manhattan heavy water plants was situated, has 6 units, providing up to 123m gal/d. The French company have also recently completed an installation for the Commisariat à l'Energie Atomique at Marcoule where a single unit is producing 310,000 gal/h by induced filtration from a small river nearby. This water is used for cooling without further treatment and is also used for drinking.

Digital counter plug-in units from Racal

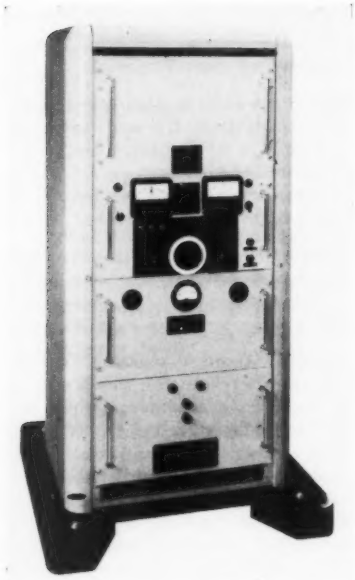
Experience has shown that the continually expanding applications of digital counting techniques in the fields of frequency and time interval measurement, batch counting, shaft speed checking etc., are so varied as to make it extremely difficult to design standard equipment to satisfy the differing requirements. Nevertheless, as a result of extensive development work, Racal Engineering Ltd, Western Road, Bracknell, Berks claim to have achieved a simple yet effective solution by the adoption of the 'plug-in unit' principle. Many applications of counting techniques have been carefully analysed and a range of suitable units have been designed. The use of these both simplifies and cheapens the manufacture of equipments to customers specifications, and in addition, Racal are offering the plug-in units alone to suit customers who may wish themselves to incorporate them into equipments.

Standard units cut cost of special equipments



The following units are available: *digital counting units*:—these are direct reading single decade electronic counters and are available covering the ranges 0-100 kc/s and 0-100 Mc/s. *Amplifier-shaper-gate*:—used to amplify and shape the input signal to a pulse suitable for passing through the gate and operating the counting units. It will accept a sine wave or a pulse input. *Frequency generator*:—contains a 100 kc/s crystal followed by a phantastron dividing circuit adjusted to divide the frequency of 100 kc/s by 10 to give a pulse output of 10 kc/s. *Dividing unit*:—this divides the input frequency by factors of ten. *Gate control*:—this receives the pulse train and converts to square pulses for control of gate. *Coincidence unit*:—provides an output pulse after a predetermined number of input pulses have been counted. Further units to be announced will be *Pulse Inverter* and *Trigger Units*.

Baldwin introduce bremsstrahlung thickness gauge



Atomat III measures steel .02 to .25 in. thick

For measuring the thickness of strip and sheet metal, the beta thickness gauge is now in widespread use but with simple beta sources the maximum thickness measurable is only about 0·020 in. steel with equivalent thicknesses in other metals. Gamma sources cannot satisfactorily be employed below about 0·250 in. in steel so there was a considerable gap from 0·020 to 0·250 in.—a most important range.

To get over the difficulty, Baldwin Instrument Co Ltd, Brooklands Works, Dartford, Kent, have recently announced a new thickness gauge, the Atomat Mk III. This uses a beta source but instead of employing the direct beta-radiation, it uses the powerful bremsstrahlung—continuous X-rays which are emitted when beta particles are slowed down by collision with matter. By this means it is now possible to measure successfully, strip steel in the range 0·020 to 0·250 in. The Baldwin range of beta, bremsstrahlung and gamma thickness gauges now measure from 0·0005 in. up to several inches of steel.

No more pipette sucking with simple new device

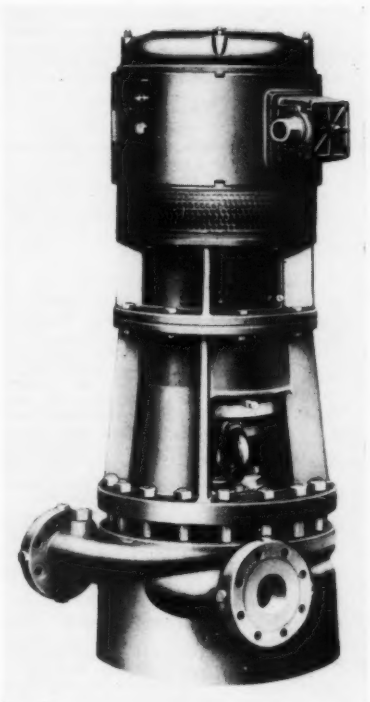
Radioactive solutions, even if only very slightly active, should never on any account be pipetted by mouth, but should be drawn in by a pipette filler. Griffin and George Ltd, Ealing Road, Alperton, Middlesex have recently introduced a very simple and inexpensive device for this purpose.

It consists essentially of a moulded rubber bulb with a capacity of 60 ml, fitted with a rubber 3-valve control unit containing plastic balls which act as valves. There are no metal parts to corrode and no fragile parts to break. It is suitable for filling pipettes of up to 100 ml. capacity. In addition to pipette filling, it can also be used as a pressure device on the reservoir of automatic burettes. The cost is 12s. 6d. (136s. a dozen).

Griffin and George pipette can be worked with one hand

New vertical Mopump for hot water has 350 psi head

When Rhodes, Brydon and Youatt Ltd, Waterloo Works, Stockport were recently contemplating a new range of hot water circulation pumps going up to 350 lb/in² they naturally drew on their experience with their well-known 150 lb/in²



Vertical layout saves space; makes easier maintenance

Mopumps which have now been manufactured for 15 years. Although the smaller pumps are of horizontal design it was decided to go for the vertical layout for the new model for the following reasons: it takes up less floor space; it is easier to get at for maintenance; the overall length is reduced because the ball and roller bearings have a shorter span; the pumps end is more rigid; the stuffing box sealing is simplified because the impeller is not overhung.

The new range of pumps—which can be designed for pressures over 350 lb/in² if required—are of cast steel with suction and delivery branches on a common centre height but offset from the axis of rotation. The impeller is of conventional single entry, double shrouded design manufactured in zinc-free bronze or of spheroidal graphite cast iron.

Reactor Physics-5

WHEN NEUTRONS ARE SLOWED DOWN by elastic collisions it was shown that energy is lost in discrete amounts, but except where the moderator is composed of very light nuclei, the simplifying assumption that energy loss is continuous can be justified. An expression is derived for the time taken for a fission neutron to slow down to thermal energy. Cases are examined in detail of slowing down in infinite capturing and non-capturing media and expression for the resonance escape probability derived.

The case of the finite non-capturing medium leads to the concept of the Fermi age of neutrons and to the derivation of the Fermi age equation. Consideration of the idea of a slowing down length leads to an expression analogous to the diffusion length.

ON A CONSTATÉ QUE, lorsque les neutrons sont ralentis par des collisions élastiques, la perte d'énergie a lieu en des quantités discrètes ; la supposition simplifiante de perte continue peut être néanmoins justifiée, sauf pour le cas d'un modérateur composé des noyaux très legers. On a dérivé une expression pour le temps qui est nécessaire afin qu'un neutron de fission soit ralenti jusqu'au niveau d'énergie thermique. On a étudié en détail les cas de ralentissement dans les milieux infinis capturants et non-capturants et l'on a dérivé une équation pour la probabilité d'échapper à la capture par résonance.

Le cas d'un milieu fini non-capturant mène à la conception de l'âge de Fermi pour les neutrons et à la dérivation d'une équation de l'âge de Fermi. L'analyse de la conception du parcours de ralentissement mène à une expression analogue à celle pour le parcours de diffusion.

ES WURDE GEZEIGT, DASS, wenn Neutronen durch elastische Zusammenstösse verlangsamt werden, der Energieverlust in sehr kleinen aber endlichen Mengen erfolgt ; doch kann die vereinfachende Annahme eines kontinuierlichen Energieverlustes gerechtfertigt werden, falls der Moderator nicht aus sehr leichten Kernen besteht. Ein Ausdruck für die zur Verlangsamung eines Spaltungsneutrons bis zur Wärmeenergie benötigte Zeit wird abgeleitet. Verlangsamungsfälle in unendlichen einfangenden und nichteinfangenden Medien werden eingehend studiert, und es wird ein Ausdruck für die Resonanzeinfangausweichungswahrscheinlichkeit abgeleitet.

Der Fall endlicher nichteinfangender Medien führt zum Begriff des Fermialters für Neutronen und zur Ableitung einer Fermialtergleichung. Die Betrachtung des Verlangsamungslängenbegriffs führt zu einem der Diffusionslänge ähnlichen Ausdruck.

CUANDO LOS NEUTRONES SON RETARDADOS por colisiones elásticas se comprobó que la energía se pierde en cantidades discretas, pero, con la excepción de los casos en que el moderador está compuesto de núcleos muy ligeros, puede justificarse la hipótesis simplificadora de que la pérdida de energía es constante. Se deriva una expresión para el tiempo que tarda en retardar un neutrón de fisión hasta la energía térmica. Son examinados en detalle casos de retardación en medios infinitos de captura y no captura y deducida una expresión para la probabilidad de escape de resonancia.

El caso del medio finito de no captura conduce al concepto de la edad de neutrones Fermi y a la deducción de la ecuación de edad Fermi. Consideraciones sobre la idea de un período de retardación conduce a una expresión análoga al período de difusión.

ДОКАЗЫВАЕТСЯ, ЧТО В СЛУЧАЕ замедления нейтронов бследствие упругих столкновений потеря энергии происходит раздельными пакетами, но это упрощающее предположение непрерывной потери можно считать позволительным, исключая случай, когда модератор состоит из огень легких ядер. Выводится выражение для времени, необходимого для того, чтобы нейтроны деления замедлились вплоть до термической энергии. Цсследуются подробно слугаи замедления в бесконечных захватывающих и незахватывающих средах и выводится выражение для вероятности избежания резонансного захвата.

Случай конечной незахватывающей среды ведет к понятию возраста нейтронов по ферми и к уравнению для этого возраста. Расомотрение понятия длины замедления ведет к выражению, аналогичному выражению для диффузионной длины.

I. The continuous slowing down model

As neutrons are slowed down from fission energy by elastic collisions in a finite system, for any particular neutron energy there will also be a particular spatial distribution of the neutrons of this energy. It is this dependence of the neutron distribution on space co-ordinates and energy that is now to be discussed.

It has been seen above that in the slowing-down process neutrons lose energy in discrete amounts, but in order to formulate a simple theory of the process the assumption is made that the energy loss is continuous.

This assumption requires some discussion. It will clearly not lead to good results where the slowing down is by very light nuclei. In such cases a neutron can lose a large part of its energy on collision (all of its energy in a head-on collision with a hydrogen atom) and so the assumption of continuous energy loss is a poor one. However, as the mass of the nuclei gets larger the approximation gets better. For example, in the case of collisions with carbon nuclei, the maximum factor by which the neutron energy can change, α, is 1·40 and the average factor, i.e. e^{ξ}, is 1·17.

Using the above picture, the number of collisions made by a neutron of velocity v in a small time dt in a medium of scattering mean free path λ_s is

$$\frac{vdt}{\lambda_s} \tag{5.1}$$

which from the definition of ξ must also be equal to

$$-\frac{d(lnE)}{\xi} \tag{5.2}$$

and so setting these equal and writing $d(lnE)$ as dE/E

$$\frac{vdt}{\lambda_s} = -\frac{1}{\xi}\frac{dE}{E} \tag{5.3}$$

Integration of this equation will lead to a value of t_o, the time between a neutron being produced as a fission neutron and it becoming a thermal neutron. The result is more conveniently expressed in terms of the neutron velocity v than the energy E, then

$$t_o = \frac{2\lambda_s}{\xi}\left(\frac{1}{v_{th}} - \frac{1}{v_o}\right) \tag{5.4}$$

where v_{th} = 2200m per sec

and v_o = fission velocity (corresponding to 2 MeV).

Now

$$\left(\frac{v_o}{v_{th}}\right)^2 = \frac{E_o}{E_{th}}$$

$$\therefore \quad v_o = v_{th}\sqrt{\frac{E_o}{E_{th}}} = v_{th}\sqrt{\frac{2\times10^6}{0{\cdot}025}}$$

by James F. Hill Senior Lecturer, Reactor School, Harwell

A useful concept in slowing down theory is the Fermi age of neutrons. NUCLEAR POWER'S basic course this month deals with this and goes on to explain how neutrons multiply in a reactor

$$\simeq 9\times 10^3\, v_{th}$$

So $v_{th} \ll v_o$ and (5.4) may be written approximately as

$$t_o \simeq \frac{2\lambda_s}{\xi}\frac{1}{v_{th}} \qquad (5.5)$$

Typical value of t_o are quoted below in table 5.1 along with values of τ_o previously quoted in table 3.1 for comparison. All times are in seconds and it is to be noted that t_o is in each case considerably less than τ_o, so that a neutron spends much more time as a thermal neutron than slowing down.

2. Slowing down in an infinite non-capturing medium

It is convenient in discussing the slowing down of neutrons to define a quantity q as the number of neutrons per unit volume which are slowed down from above to below the energy E per unit time. q is known as the slowing down density, is usually measured in neutrons per cm³ per sec and in general is a function of the neutron energy and of position.

In the case of an infinite non-capturing medium with a uniform production of neutrons no neutrons can be lost from the system either by leakage or capture and therefore q must be a constant. So in time dt, $q\,dt$ neutrons per cm³ will cross the energy E. Then if $\phi(E)\,dE$ is defined to be the flux of neutrons whose energies lie in the range E, $E + dE$,

$$\phi(E)\,dE = -\,q\,dt\,v$$

as dE is negative if dt is positive, and so from (5.3)

$$\phi(E)\,dE = \frac{q\lambda_s}{\xi}\frac{dE}{E} \qquad (5.6)$$

This shows that if the scattering mean free path λ_s is constant, the neutron flux is proportional to E^{-1}.

3. Slowing down in an infinite capturing medium

Suppose now the medium remains infinite in extent but captures neutrons. Then consider for the moment

moderator	t_o	τ_o
C	$1{\cdot}5\times 10^{-4}$	$1{\cdot}26\times 10^{-2}$
H_2O	10^{-5}	$2{\cdot}1\times 10^{-4}$
D_2O	$4{\cdot}6\times 10^{-5}$	$0{\cdot}15$
Be	$6{\cdot}7\times 10^{-5}$	$3{\cdot}7\times 10^{-3}$

Table 5.1 ***diffusion and slowing down times***

(5.6) written in the form

$$\Sigma_s\ \phi(E)\,dE = \frac{q}{\xi}\frac{dE}{E} \qquad (5.7)$$

The left hand side represents the number of neutrons scattered per cm³ from the energy range E, $E+dE$. Consequently because there is no neutron loss from this energy range the right hand side must represent the number of neutrons per cm³ scattered into the range.

In the case of a capturing medium the equation of neutron conservation is ;

neutrons absorbed in energy range
+ neutrons scattered from energy range
= neutrons scattered into energy range

and so by analogy with (5.6) this can be written as

$$\left[\ \Sigma_a\ (E) + \Sigma_s\ \right]\phi\,(E)\,dE = \frac{q(E)}{\xi}\frac{dN}{E} \qquad (5.8)$$

where $q = q\,(E)$ is now a function of the neutron energy. It has also been assumed in writing (5.8) that the absorption cross-section is a function of the neutron energy but the scattering cross-section is not.

Furthermore, as neutrons cross the energy range they are only removed by absorption and so the change in $q\,(E)$, $dq\,(E)$ across the range must be equal to the number of neutrons absorbed in the range, and so (leaving out a minus sign on both sides of the equation as dE and $dq\,(E)$ are both negative)

$$\Sigma_a\,(E)\ \ \phi\ (E)dE = dq(E) \qquad (5.9)$$

and on dividing (5.9) by (5.8)

$$\frac{1}{\xi}\cdot\frac{\Sigma_a\,(E)}{\Sigma_a\,(E)+\Sigma_s}\cdot\frac{dE}{E} = \frac{dq\,(E)}{q\,(E)}$$

and assuming ξ is energy independent

$$\frac{1}{\xi}\int_E^{E_o}\frac{\Sigma_a\,(E')}{\Sigma_a\,(E')+\Sigma_s}\cdot\frac{dE'}{E'} = \ln\frac{q\,(E_o)}{q\,(E)} \qquad (5.10)$$

where E_o is fission energy.

Now $q\,(E_o)$ is the number of fission neutrons produced per cm³ per sec. and $q\,(E)$ is the number of neutrons per cm³ per sec. crossing the energy E. The ratio $q(E)\,/\,q(E_o)$ therefore represent the fraction of fission neutrons which reach energy E without being captured. This quantity is called the resonance escape probability to energy E and is written $p(E)$. In the particular case where the

lower energy is thermal energy E_{th}, $p(E_{th})$ is written simply as p and called the resonance escape probability. Thus

$$p = \exp\left[-\frac{1}{\xi} \int_{E_{th}}^{E_o} \frac{\Sigma_o(E)}{\Sigma_a(E)+\Sigma_s} \cdot \frac{dE}{E} \right] \qquad (5.11)$$

4. Slowing down in a finite non-capturing medium

In this case the argument is similar to that in the previous case but now the change in q is a result of neutrons being lost by leakage instead of by capture. So by analogy with the leakage calculated for thermal neutrons (see (2.39) and (2.44))

$$\frac{\lambda_t}{3} \nabla^2 \phi(E)\, dE = dq(E) \qquad (5.12)$$

Now the form of $\phi(E)\, dE$ for a non-capturing medium is given by (5.7) and so substituting this into (5.12) leads to

$$\frac{\lambda_t}{3\xi \Sigma_s E} \nabla^2 q(E) = \frac{dq(E)}{dE} \qquad (5.13)$$

and introducing a new variable $\tau(E)$ defined by

$$d\tau(E) = \frac{\lambda_t}{3\xi \Sigma_s E} \cdot dE \qquad (5.14)$$

(5.13) becomes

$$\nabla^2 q = \frac{dq}{d\tau} \qquad (5.15)$$

where q is now a function of the space coordinates as well as of the energy.

Integration of (5.14) yields

$$\tau(E) = \int_E^{E_o} \frac{\lambda_t}{3\xi \Sigma_s} \cdot \frac{dE'}{E'}$$

$$= \frac{1}{3\xi} \int_E^{E_o} \lambda_s \lambda_t \frac{dE'}{E'} \qquad (5.16)$$

The quantity $\tau(E)$ is known as the *Fermi age* to energy E, and the equation (5.15) as the *Fermi age equation.*

$\tau(E)$ has, from (5.16) dimensions of the square of length and increases as E decreases. Thus for neutrons which are " older ", that is have smaller energies, τ is larger. In the particular case of $E = E_{th}$, $\tau(E_{th})$ will be written as L_s^2 where L_s is called the slowing down length, so

$$\tau(E_{th}) = L_s^2 \qquad (5.17)$$

5. Slowing down of a point source of fast neutrons and the physical significance of the slowing down length.

For a point source emitting Q fast (fission) neutrons per sec. at the origin in an infinite medium, the solution of (5.15) is

$$q(r,\tau) = \frac{Q}{(4\pi\tau)^{3/2}} \, e^{-r^2/4\tau} \qquad (5.18)$$

This is a Gaussian distribution about the origin, the shape of which depends on τ. For small τ, that is for neutrons which have not suffered much slowing down, the distribution is concentrated round the origin, but for larger values of τ the distribution is more spread out, as would be expected on physical grounds.

The spreading out of the distribution as τ increases suggests that τ is connected with the distance a neutron travels in being slowed down to age τ. In discussing the diffusion of neutrons it was found that the diffusion length L was connected with the mean square distance a neutron travelled (see (3.21)). The mean square distance $\bar{r}^2(\tau)$ a neutron travels in slowing down to age τ is then given by

$$\bar{r}^2(\tau) = \frac{\int_0^\infty r^2 q(r,\tau)\, 4\pi r^2\, dr}{\int_0^\infty q(r,\tau)\, 4\pi r^2\, dr} \qquad (5.19)$$

where $q(r, \tau)$ is given by (5.18). This yields

$$\bar{r}^2(\tau) = 6\tau \qquad (5.20)$$

In the particular case where the final energy is thermal $\tau = L_s^2$ and so

$$\bar{r}^2(L_s) = 6L_s^2 \qquad (5.21)$$

analogous to (3.21).

A further similarity between the slowing-down length and diffusion length can be shown by referring back to (5.16). Suppose $E = E_{th}$ and taking average values of λ_s and λ_t, (5.16) yields

$$L_s^2 = \frac{\lambda_s \lambda_t}{3\xi} \ln \frac{E_o}{E_{th}} \qquad (5.22)$$

$$= \tfrac{1}{3}\lambda_t \lambda_s \text{ (number of collisions made in slowing down)} \qquad (5.23)$$

using (4.20). This is to be compared with the similar equation (3.24) in diffusion theory.

Typical values of L_s^2 are quoted below in table 5.2.

6. Slowing down in a finite capturing medium

It can be shown that if q_a is the slowing down density in a medium with absorption, then if q is the slowing down density in the medium without absorption

$$q_a = pq \qquad (5.24)$$

with

$$\nabla^2 q = \frac{\partial q}{\partial \tau} \qquad (5.25)$$

as before.

material	L_s^2
H_2O	33 cm²
D_2O	120 "
Be	98 "
C	350 "

Table 5.2 ***slowing down lengths***

Neutron multiplication

7. The multiplication cycle

We have investigated the behaviour of diffusing and slowing down neutrons and have formulated the equations giving their spatial distributions. The next stage is to apply these equations in the appropriate form to the behaviour of neutrons in a reactor.

However, before doing this we must investigate the multiplication of neutrons in a medium containing fissionable and non-fissionable materials. In order that we do not, at this stage, need to consider the escape of neutrons from the system it will be assumed to be infinite in extent. (A finite system will be dealt with later). Also for simplicity the fissionable material will be taken to be uranium and this will be referred to as the fuel. Further it will be supposed that substantially all the fissions are caused by thermal neutrons.

Starting then with one neutron produced in fission, as a fast neutron from U^{235} fission, if the fuel is lumped in any way there will be a chance that before it escapes from the lump in which it is produced it may make a further fission in U^{238} (See article 1 ¶ 7, NUCLEAR POWER, Vol 1, No 1, p. 37). In order to take account of this a fast fission factor ε is defined as

ε = average number of fast neutrons produced per one neutron from thermal fission (5.26)

Thus there are ε fast neutrons which will then be slowed down by the moderator. However, some of these will be captured in resonances in U^{238} and for convenience it is assumed that this capture takes place immediately above thermal energies. So a resonance escape probability p is defined by

p = fraction of fast neutrons becoming thermal in an infinite system (5.27)

so that $1-p$ is the fraction of neutrons captured by resonance.

εp neutrons then become thermal and will be absorbed by the materials of the system, some wastefully and others by the fissionable material. It is customary to deal in terms of the number of neutrons absorbed by the fuel and not those absorbed by the fissionable material, so if f is the fraction absorbed by the fuel

$$f = \frac{\text{thermal neutrons absorbed by fuel}}{\text{total thermal neutrons absorbed}} \qquad (5.28)$$

and then a total εpf thermal neutrons are absorbed by the fuel. If η fission neutrons result directly from the absorption of one thermal neutron by the fuel, $\varepsilon pf\eta$ fission neutrons finally result. Thus the one original fission neutron has become $\varepsilon pf\eta$ and this quantity is called the multiplication constant k_∞ of the infinite system. It is convenient to write this simply as k, so,

$$k = \eta\varepsilon pf \qquad (5.29)$$

If N(25) and N(28) respectively are the number of atoms of U235 and U238 per unit volume of uranium, ν the number of neutrons per fission of U^{235} then, from the definition of η above

$$\eta = \frac{\nu N(25)\sigma_f(25)}{N(25)\sigma_a(25) + N(28)\sigma_a(28)} \qquad (5.30)$$

which, if we assign an average fission cross-section $\sigma_f(U)$ to a uranium atom irrespective as to whether it is U^{238} or U^{235} defined by

$$\sigma_f(U) = \frac{N(25)\sigma_f(25)}{N(25) + N(28)} \qquad (5.31)$$

and a similar average absorption cross-section $\sigma_a U$ defined by

$$\sigma_a(U) = \frac{N(25)\sigma_a(25) + N(28)\sigma_a(28)}{N(25) + N(28)} \quad , \qquad (5.32)$$

then

$$\eta = \frac{\nu\sigma_f(U)}{\sigma_a(U)} \qquad (5.33)$$

Similarly, a value $\eta(25)$ can be defined for U^{235} alone as

$$\eta(25) = \frac{\nu\sigma_f(25)}{\sigma_a(25)} \qquad (5.34)$$

Table 5.3 quotes cross-section and η values for natural uranium.

Returning now to the multiplication constant k as defined by (5.29). It is clear that if, in an infinite system $k = 1$ then the neutron chain reaction will just maintain itself—the number of neutrons in the system staying constant. Such a state, when applied to a reactor of finite size, is referred to as the critical state or the reactor is said to be critical. Clearly, for a reactor to be critical k must be larger than unity to make up for the additional inevitable loss of neutrons from the sides of the reactor.

Returning to the infinite system if k is greater than unity the neutron population will steadily increase and the system is divergent or super-critical. For k less than unity successive generations of neutrons do not reproduce themselves and so an initial neutron population will gradually die away to zero. The system is the convergent or sub-critical.

It is necessary to be able to calculate the value of k and hence its individual components for any type of system. Two essentially different cases arise. The first, and simpler one, is that in which all the constituents are mixed intimately to form a homogeneous system. The second is a heterogeneous system where the different materials are separate from each other. The calculation of k for this system will not be discussed here.*

	parts by atom	σ_f	σ_e	σ_a	ν	η
U^{235}	1	580	107	687	2·46	2·08
U^{238}	138	0	2·75	2·75	—	—
Natural uranium	—	4·17	3·50	7·67	—	1·34

Table 5.3 ***constants for natural uranium*** *the cross-sections are in barns per atom at 2200 m/sec.*

* For details of the calculation of k for a heterogeneous system see AERE R/R 922 *Natural Uranium Graphite Lattices*, E. A. Guggenheim and M. H. L. Pryce. H.M.S.O.

The next instalment will deal with the value of k for various systems

Power station computer

WHAT IS CLAIMED to be the most comprehensive nuclear power station simulator yet built in Britain is a central feature of the research laboratories and design centre of the G.E.C. Simon-Carves Atomic Energy Group at Erith, Kent. Designed and built for the group by Elliott Brothers Limited, of Boreham Wood, Herts, the machine is an electronic analogue computer which can be adapted to study the performance of any type of reactor. The computer is, however, only a part of what is now a very extensive research laboratory.

At a luncheon on August 16, Mr. R. N. Millar, the Group Manager, in welcoming the guests gave a brief outline of its history. When the White Paper was issued in February 1955, the firms invited to tender for the first CEA power stations at Bradwell and Berkeley had just 12 months to fix the design parameters and a further 6 months to finalize the design. Since, unlike Calder Hall, these stations had to be optimised for power production, the design problems were in many cases radically different and the GEC's first task, said Mr Millar, was (a) to plan a research and development programme which would be of most direct use and (b) obtain sufficient staff to carry this out. These problems he assessed as being those of heavy mechanical engineering, heat transfer and metallurgy. The Group's staff is now 200 of whom about half are of graduate status. In addition, it has the facilities of the whole GEC for specialised work. Mr Millar said the Group believed in centralization and so both the research laboratories and the design drawing office were located under one roof at the Fraser and Chalmers Engineering Works of the GEC, where the firm's heavy mechanical work is done.

Compatibility studies

The laboratories are essentially "cold" ones since no radioactive material is handled: when "hot" tests are required, these are done in one of the UKAEA establishments. In the metallurgical laboratories a battery of GEC vertical heat treatment furnaces is installed. These contain a stainless steel autoclave in which compatibility tests of metals in CO_2 and CO atmospheres are carried out. The effect of small amounts of moisture can also be studied. Among the canning materials studied are magnesium and zirconium alloys: alloys of beryllium and niobium will be investigated later. It has been found that the magnox alloy used in the Calder Hall reactor is satisfactory in CO_2 up to very nearly 500°C, the limit being set not so much by oxidation as by creep resistance. Furthermore, it is now considered by the Group that the upper limit to reactor temperatures will be set by the fuel rod itself rather than by the can. A special quartz spring thermobalance has been developed for the rapid measurement of oxidation rates in CO_2.

The cooling fins on fuel cans are subjected to bending stresses by the gas flow and a test rig is installed to investigate this. Stress corrosion is also being studied and a battery of special machines is being installed for this purpose. The first tests will be on magnesium in carbon dioxide atmospheres but the equipment is suitable for other materials and corrosion media. A GEC 25kW high-frequency furnace is installed in the metallurgical laboratory and is used for melting small amounts of experimental alloys. It can also be used with controlled atmospheres. An interesting rig is a British Oxygen argon-arc welding machine adapted to the semi-automatic welding of fuel can end caps.

Heat transfer work

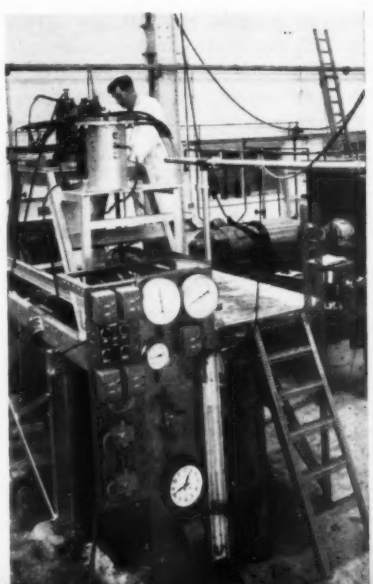
Considerable work has been done by the Group on heat transfer and a well-equipped laboratory is available for this work. The work is necessarily of a highly *ad hoc* nature and so far has been directed toward producing (a) a fuel can, (b) a heat exchanger tube. Two rigs are used for the former work and reactor conditions are simulated by replacing the uranium rod by a stainless steel heating element inside the can under test. The larger rig simulates working conditions in a fuel channel by using a long copper pipe, lagged and supplied with CO_2 from *Cardice* generators by a steam turbine driven blower. The heating current is supplied from two DC generators and measurements are made of can temperature, gas flow and pressure drop. There is also a smaller rig which uses air at atmospheric pressure instead of carbon dioxide.

A whole series of fuel can extended surfaces have been investigated most of which take the form of multi-start helical fins of varying pitches. Very small pitch angles appear to be generally favoured.

For the steam-raising heat exchangers, owing to the low temperature of the gas compared with that in a combustion boiler, the design of extended surface tubes presents many problems. At Erith, a wind-tunnel has been constructed in which transfer rates, head loss and other important design data may be obtained. Owing to the difficulty of working with hot gas, the heat flow is reversed. Coolant air passes the experimental tube banks and heat is extracted from superheated steam in the tubes. Measurement of condensate provides a convenient method of quickly obtaining heat transfer rates. Numerous designs of stud tubes and other forms of extended surfaces have been studied in this way.

Another interesting apparatus located in the heat laboratory is a rig for testing control rod drives and a high steel structure enables withdrawal rates and accelerations to be studied. A demonstration showed how a rod is quickly dropped in under emergency conditions and yet brought to rest gently at the end of its travel.

Other test rigs are used for developing and prototype testing of portions of charge and discharge equipment, gas selection valves, special viscosity gas seals for carbon dioxide blowers, mechanical and electrical drive units which can operate in hot gas and bearings which can



A prototype viscosity gas seal for carbon dioxide blowers undergoes trials on a special test rig

installed at GEC Simon-Carves

Group research laboratories shown

be run without conventional lubrication.

The analogue computer

The Elliott analogue computer has been designed to solve problems associated with gas-cooled graphite-moderated reactor stations, although the flexibility of the machine will allow its use in the study of other types of reactor also. Initially, its main application will be in the study of transient phenomena following disturbances such as fault conditions, and in the analysis of automatic control systems. The new computer is housed in its own room, the air in which is maintained at slightly above atmospheric pressure so as to minimize the ingress of dust.

The machine comprises a total of eight cabinets, arranged in 'L' formation with the control cabinet at the junction. One special cabinet is permanently connected to simulate the reactor, and the remaining six are identical general-purpose cabinets which can be set up to simulate the performance of heat exchangers, control rods, blowers, turbo-alternators or other components of the power plant. This arrangement allows the equipment to be used with a high degree of flexibility, and will enable a wide variety of problems to be studied.

Provision is made for the incorporation of 100 drift-corrected amplifiers and 20 servo-multiplier units. At present 84 amplifiers are available, any one of which can be used as a summing amplifier, integrator, or servo amplifier. Two transit time units are provided for the simulation of time delays, the output signal of each unit being the input signal delayed in time.

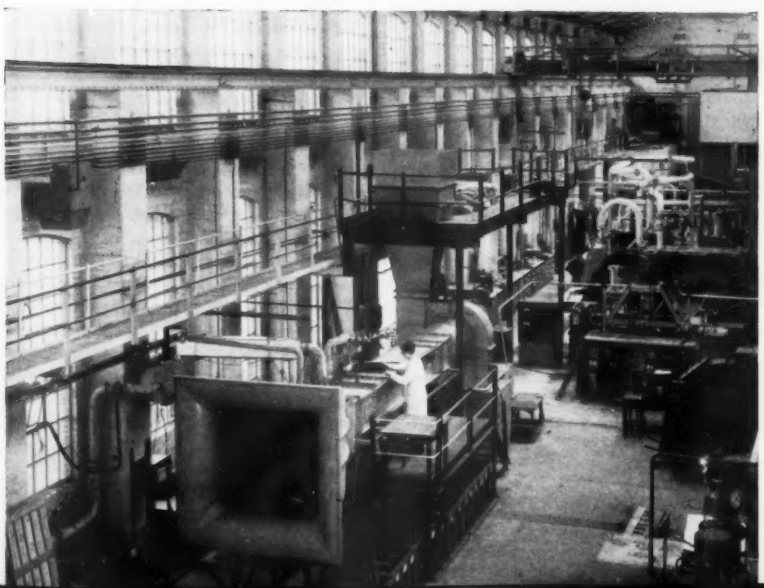
In many of the problems encountered the time scale is likely to vary from a fraction of a second to several hours. The computer normally operates in real time and the performance of any section of the power station can be examined from the traces of two continuous high-speed pen recorders which allow four variables to be recorded simultaneously. Alternative indication of each section is provided by a cathode-ray oscillograph. An additional advantage of real time working is that actual units of a control system can be connected to the simulator and their behaviour analyzed. For longer-term problems (such as determining the effects of poisoning in the fuel) the rate of working can be accelerated.

An important feature of the computer is its ability to operate either as one large machine or as two completely independent smaller machines. It is thus possible to examine simultaneously two entirely separate problems, a considerable time-saving advantage where neither problem requires the use of the complete machine.

The D.C. amplifier units have a range of -100V to $+100$V and use Bristol's *Syncroverter* choppers. Long-term drift is less than $\pm 100\ \mu$V and effective grid current is less than 10^{-11}A. The Servo-Multipliers are plug-in units and, operating directly from the computing amplifiers, will multiply up to 5 quantities. Adjusted for best step response (50 milliseconds rise time, 6 per cent overshoot) natural frequency is 13 c/s. Adjusted for best frequency response, natural frequency is 30 c/s. Time lag in coolant temperature transfer between the reactor heat exchanger and the main heat exchanger may be simulated between 2 and 60 seconds. Variation can be by manual control or from a computed signal. The reference power units provide $+100$V and -100V supplies at 0.5A with stability better than 0.1 per cent.

The Reactor Kinetics cabinet is permanently wired for 6 reactor kinetics equations with 5 groups of delayed neutrons. Delay constants and delayed neutron fractions are set in by manual controls. On the cabinet, amplifier and multiplier inputs and outputs are brought to a series of sockets on a patch panel which is engraved to show, in block diagram form, the function of each socket. Coefficients and initial conditions are set in by means of wire-bound potentiometers. Automatic clamping occurs whenever an amplifier output reaches its limit of ± 100V. The clamping disconnects all integrator inputs and holds the outputs long enough for voltages to be measured prior to rescaling.

A feature of the heat transfer laboratory is a wind tunnel in which various designs of heat exchanger tubing is tested with live steam. Further back, fuels cans are tested under simulated thermal conditions



Enquiries from abroad

Addressing the guests after luncheon, Mr Arnold Lindley, a GEC Director and General Manager of the Fraser and Chalmers Engineering Works, disclosed that his Group had already spent well over £1m on the atomic energy project and that current expenditure was running at over £½m per annum. He said that the Group's designs for the Berkeley and Bradwell stations were finalised and were now being prepared for submission to the CEA by October 1. It is understood that the two designs are essentially identical, subject only to variation dictated by site layout. Reports that the GEC reactors were to be in a spherical shell were not confirmed but it was understood that the shell would be about 3 in. thick, and that the output would be well over twice as much as Calder Hall. The firm also confirmed that, unlike Calder Hall, their CEA design had provision for charging and discharging fuel elements without shutting down the reactor.

Enquiries had been received from nearly every country in the world—serious ones from Australia, South Africa and Japan—but he thought it unlikely that these would be very firm until some experience had been obtained with Calder Hall. Associated with GEC and Simon-Carves in the Group are the Motherwell Bridge and Engineering Co Ltd and John Mowlem Ltd.

Report from Vienna–2

by a special correspondent

The Fifth World Power Conference

CORRESPONDING to the trends recorded in power plant design, improvements in boiler plants were reviewed in Division III Section G_2. A steady rise in available steam temperature of about 10°C per year is found since the fourth Conference in 1950, reaching now to 650°C, although most new plants actually use temperatures at least 50-100°C lower than this. Opinions are, however, expressed that materials are available for boiler temperatures up to 700°C. There is a steady increase in size of individual boilers up to 2,400,000 lb/hr, and efficiencies of at least 90 per cent with availabilities of nearly 100 per cent "are no longer exceptional." The universal need for burning low-grade fuels has provoked considerable attention to the fouling and corrosion of the heating surfaces, but although it is stated that the adherence of liquid slag can now generally be avoided, the sintering of fly ash remains a problem, while the extension of oil firing has its own difficulties due to vanadium and sulphur content of the fuel. Also, with the higher pressures, feed water treatment is becoming more critical, competition between evaporative treatment and demineralisation having been decided in favour of the latter for supercritical plants. In these high pressure plants, the superheater surface approaches 50 per cent of the total heat transfer area, and attention is particularly aimed at avoiding the risk of high temperature rises in the tube wall under varying load conditions. This is regarded as of far greater importance than achieving high heat transfer rates, and the later stages are therefore heated by convection rather than by radiation. In verbal discussion the need for flow stabilisation in once-through boilers, and the use of flow stabilisers with balance weight throttling cones was mentioned. The high heat transfer rates and the possibility of low water speeds at high pressures can result in film evaporation which may encourage salt deposition on the tube walls. Temperature control is of increasing importance because at the high temperatures of operation, permissible stress levels in the tubes are very sensitive to increase of temperature. The combined effects of several methods available are said to allow virtual constancy of steam temperature down to half load. The high boiler availabilities mentioned earlier have been attained in the face of low grade fuel usage, largely by developments of on-load cleaning methods. Regarding boiler construction it is accepted that the "outdoor construction" so widely used in the U.S.A. has been reduced to "semi-outdoor" for European purposes; here the boiler is used as a structural basis for the boiler house.

The steady increase in power plant efficiency which accompanies increase in steam temperature and decrease in flue gas temperature is recognised, but further advances here meet very severe difficulties and it is considered that the increase in initial conditions shows signs of slowing down and reaching, as it were asymptotically, 8,500 lb/in² and 800°C, while corrosion dangers and the need for excessively large heat transfer surfaces limits the reduction in flue gas temperature which is to be expected. It seems that atomic energy developments, with their own special problems of steam raising, will outdistance and at the same time inhibit the further development of conventional boiler plants. Particular attention was directed to the difficulties of design of a sodium to water heat exchanger, or boiler, a problem which, because of the radioactivity of the primary coolant, the desire for high heat transfer rates, the uncertainty as to the importance of the chemical reaction between sodium and water, has so far only had rather unsatisfactory solutions.

Trends in Turbine Design

The most obvious change has been the rapid increase in unit size, and the standardisation of frame sizes. The increase in steam temperatures and pressures has necessitated most careful attention to design, both as to principles and to details. The control of thermal expansions is rendered acute by the use of austenitic steels for the first stage rotor disc, blades and diaphragms and it is becoming frequent practice to use a two-shell construction together with full steam admission, a symmetrical arrangement of stop valves and means for preheating and cooling. The stresses in the high-pressure section are recognised as being due more to thermal gradients than to centrifugal forces. The protection of the turbine against overspeed is recognised in the attention paid to governor and stop-valve design, including of course the protection valve where the reheated steam returns to the turbine from the boiler, for there is sufficient energy stored in this amount of steam which has passed to stop valve to cause serious overspeeding.

Considering the present temperatures of reactor coolants, particular interest attaches to the discussion of the maximum size of turbine exhaust blading. Here it is that the use of 3000 rev/min machines in Europe has advantages compared with the American 3600 rev/min machines, a difference reflected in the practice in regard to compounding, where the Americans are given to the use of combined 3600 and 1800 rev/min sets.

Air-cooled condensers

Consideration of the continuity equation shows this to be a basic feature of turbine design. Particularly interesting is the report of quite big increases in exhaust area in recent years. The importance of wetness in the low-pressure stages is twofold, it has harmful effects both on efficiency due to the water droplets striking the backs of the blading, and on the life of the blade due to erosion, this of course also leading to a secondary but very important reduction in efficiency. Much scientific investigation is called for to assist in the solution of these problems.

The increasing difficulty of obtaining suitable condenser cooling water leads to efforts to use air cooling for closed water circulation, but although some promising work has been reported both from Germany and Hungary, and development work is preceeding on medium sized units of about 30 MW the heat transfer surface is still greater and the vacuum not so good compared with normal installations.

Governing becomes more difficult with higher steam pressures and thus a worsening of the relationship between stored energy available in the steam, and rotor inertia. Following refinement in the mathematical analysis of governing systems is a tentative but most interesting suggestion to introduce electric governing of steam turbine—perhaps an alternative stronghold for the electronic specialists to scout!

Solid coupling of turbine and generation is now general, and the importance of close inspection of the generator rotor was remarked upon. Development of hydrogen cooling has led to its use at pressures as high as 6·3 atmospheres in the U.S.A., with consequent increase in generator output for a given size of

frame. Developments were reported in the gas turbine field, but it does seem that their field of application in power stations is limited to peak load duties. On the other hand, the use of gas turbines in industrial power generation is becoming established practice and a number of interesting studies of combined steam and gas turbine cycles for such appreciations were presented.

Interest in nuclear power

Although mention of nuclear power plants occurred occasionally in Section G reports, the main discussion centred on the papers presented to Section J. The attendance on this day was extremely large and the number of speakers in the discussion was also high.

However, it is doubtful if either the papers themselves, or the discussion reached the level of technical detail as in the other Sections. This is understandable if it is realised that the papers were written in the period of exhaustion immediately after the Geneva conference, and also that in practically every case the papers were aimed at a technical but non-specialist audience, and the discussion which took place was also appropriate to this setting. In spite of this, the inclusion of a full day's discussion was well justified.

The papers and discussion show differences in approach both between countries with nuclear programmes and between this group and the other countries. The first group is concerned to report on current position and attitude, while the other group asks questions best summarised by Prof. Münzinger (Germany) namely:—

1. What highest permissible temperatures of the cooling medium for reactors may be obtained within the next 10 to 15 years?
2. What may be the highest thermal efficiencies of turbines in atomic power stations in the next 10 to 15 years?
3. What economic prospects exist for atomic power stations in various countries?

It proved easier to ask the first two questions than achieve answers, but in spite of this the general conclusion was reached that in specific cases question 3 can be answered at the present time. In Paper J.13, Duckworth, Squire and Newman of the C.E.A. speak of necessary extensions to generating capacity which will be met very largely by nuclear stations. In the discussion, J. V. Dunworth (Harwell) referred to progress in the UK on the understanding of fuel cycles and their effect on generation costs, while H. H. Gott (Risley) stated that preliminary trials of the first Calder Hall reactor had shown higher reactivity than had been calculated, and also greater effectiveness of the control rods. These, together with the satisfactory behaviour of the mechanical features of the plant, gave added confidence to a power programme based on reactors of similar type, though the reactors to be built for this programme would be larger and more economic than Calder. Kasatchowski reported satisfactory and trouble-free operation of the Soviet 5 MW station and mentioned the design of large plants using thermal reactors with up to 600 MW output. Staebler discussed the progress in the US, and in particular the increase in interest shown by private industry. There was a strong interest in small power plants.

Lindsberg made a sober but enthusiastic appraisal of possibilities and speaking for the generation industry described the benefits of the association of nuclear power and district heating systems, examples of which would be in operation in Sweden in the early 1960's.

Novel Russian proposal

Contributions to the discussion on heat utilisation were made largely from the Continent, being discussed by Münzinger, Melan, Keller, while speakers from the US, Great Britain, Russia and France for example appeared more concerned with getting the heat out of the reactors than stating acceptable temperatures for its delivery. Wootton, Great Britain, pointed out that the low steam conditions used at Calder were peculiar to that plant and that a considerably more economic cycle could be used in different circumstances.

Kasatchowski said that to speak only of thermal efficiency was misleading. The effectiveness of the conversion of potentially fissionable material into energy was the most important. He proposed the discussion of a uniformly acceptable criterion for these parameters. Such an approach led to the conclusion that thermal reactors were greatly superior to fast reactors. Styrikovitch spoke of a plan for a gas-cooled, heavy-water-moderated reactor with a gas outlet temperature of 450°C in which the moderator is kept cool (below 100°C) by an additional concentric coolant passage. The coolant is under a high pressure which is presumably carried by the outer annulus coolant tubes. Heavy water as moderator was also favoured, either with heavy water or gas cooling, by Jungnell, because of the very high cost of uranium in Sweden.

Goodlet, Great Britain, was concerned at the relatively small amount of attention paid to reactor safety and particularly to containment, in the papers and discussion. Although the Calder type of reactor is considered to be extremely safe, he regarded such questions as a matter for urgent international discussion. Naumann, Germany, expressed similar thoughts even more forcibly; the protection of workers against radiation must be treated most seriously, which led McLean of Risley to state emphatically that the industry is not in any way underestimating this problem: a great deal has been done in all British plants where the average cost of protection of workers has so far been very high. Previously, Fair (Windscale) had reported satisfactory conduct of maintenance operations on the piles situated there.

American speakers Leclair, Martin and Griswold mentioned the designs of reactor with which they are concerned. The 180 MW boiling water has modified fuel elements and pressure vessel, but higher steam conditions; the sodium graphite reactor is now considered promising for outputs greater than 60 MW electrical, while organic liquids are thought useful for smaller outputs. The Detroit Edison fast reactor is being re-examined in respect of the core temperature coefficient.

The general conclusion was reached that although in the absence of extensive experience it is never practicable to speak of costs with any certainty (and nuclear power is not likely to violate this rule!) yet the time has come when the technique is available to any country which really finds a necessity for it, and under these special circumstances it is likely that the cost will be reasonable, viewed in relation to the trend of costs involving conventional fuels.

Impressive hydro plants

There are many point of common interest between nuclear and hydro-power, and a brief review of the subjects discussed under this heading may be useful. In Section B we mentioned the large resources awaiting exploitation in Asia and Africa, and certainly the scale of operation of the hydroelectric engineer is to be respected — perhaps for the mechanical plant he installs, such as, say, the turbines for the Quebec Hydro Electric Commission, for which the head is 875 ft, 175,000 b.h.p. output at 277 rev/min—the "straight flow" rotary valves for this turbine are 7 ft 9 in bore—perhaps for his civil engineering work, such as the dam work reported by Nillson of the Swedish State Power Board. Nillson states, "the tunnel blasting technique has developed rapidly in Sweden, due to intimate cooperation between manufacturers of drilling machines and hard metal drills, and Swedish builders of power plants and mines.... An idea of the advance is shown in the costs for two discharge tunnels at Forsaco. One 150 m^2 area was built in 1946-47, the other 170 m^2 in 1954-5. Both are about 1 km long and run parallel and are in the same kind of rock. The first one cost 18 Kr/m^2, the other one 22 Kr/m^2 but the

price level has during these years gone up 100 per cent, wherefore the real cost has dropped considerably."

The use of liquid coolants in reactors provokes attention to hydraulic experimentation equally with aerodynamics, and a number of papers touched on this subject, at least to show that problems met by reactor engineers may be well known to hydraulics engineers. Here may be mentioned a paper by Braikevitch of Great Britain.

The construction of large dams involves of course site organisation of very high calibre, and papers H4, H11 and H40 may be of interest in this connection. Like H3 which deals with tunnelling theory and practice they are in German. It is of interest to read that large dams can now be erected with a daily placing of concrete of 20,000 m^3 (of the order of 40,000 tons) per day. A paper by Fulton, Haldane and Mountain mentions the important relation between nuclear power and pumped storage schemes for countries with suitable topography. This point was emphasised in discussion by Gilbrat (France) who emphasised the importance of the development of reversible sets.

' Other sources ' discounted

Russian speakers surveyed the methods in use for reduction of construction costs, including standardization of design, great emphasis on continuity of work even through the winter, new types of shuttering such as precast concrete plates or close mesh wire netting. Welding of large turbine parts has resulted in large saving of weight.

In Section K were dealt with "other sources of energy", and it is fairly clear from the papers, the general report of Professor Thirring and from the discussion that there is little real likelihood of a significant contribution to world power supplies from any of these sources such as solar radiation, fuel cells, high pressure CO_2 from the ground, or thermal springs. For technical interest, however, the paper on heat pump development in Great Britain, by Miss M. V. Griffith and J. A. Sumner, and the paper on fuel cells, by Bacon and Forrest, and a paper on the economics of multi-stage evaporation may be mentioned.

Sections L and M dealt with the purification of waste water and gases in the production and use of energy, and here were mentioned the special problems and responsibilities of atomic energy projects. The paper of McLean, Dunster and Fair of the United Kingdom Atomic Energy Authority gave a very realistic survey of this question, although it was actually dealt with in Section J.

In this report we have tried to mention a reasonable number of the points of interest in a very wide range. We recommend for further reading, firstly the general reports of the various sections, but particularly Sections $G_{1,2,3}$, Sections H_1 and H_2, Sections J_1 and J_2. In these, the Austrian reporters give a masterly summary of the subject matter, particularly considering the difficulties of their position in Section J.

NAMES IN THE NEWS

T. B. Webb

W. R. Wootton

W. B. Carlson

J. T. W. Dewar

Mr T. B. Webb *BSc (Eng) MIMechE, MASME has been appointed Chief Engineer and Manager of the newly-formed Atomic Energy Department of Babcock and Wilcox Ltd (see news story this issue). Mr Webb has for some years directed the activities of the Babcock research centre at Renfrew and has been closely connected with the firm's investigations into the applications of nuclear energy to power production. As Assistant Manager of the new department,* **Mr W. R. Wootton** *has been appointed. Mr Wootton, who is one of the company's senior engineers, is well known in nuclear energy circles both here and abroad and has been closely associated with the AEA in feasibility studies for atomic developments. He was also closely connected with the Babcock steam-raising plant at Calder Hall. At Renfrew,* **Dr W. B. Carlson,** *DSc, MIMechE takes over Mr Webb's old post.*

Mr J. T. W. Dewar *MIMechE, AMIProdE was appointed an additional director of the English Steel Corporation Ltd on Sept. 1. Mr Dewar is also Deputy Managing Director of Firth-Vickers Stainless Steel Ltd and Managing Director of Shepcote Lane Rolling Mills Ltd. He started as a works pupil with Vickers Ltd in 1925, transferred to Firth-Vickers Stainless Steel Ltd in 1934, to Thos. Firth and John Brown in 1939. He became deputy managing director of Firth-Vickers Steels Ltd in 1946 and in 1950 was made Managing Director of Shepcote Lane Rolling Mills Ltd.*

Mr James F. Widman *has joined the board of Union Carbide Ltd.*

Mr S. Polkinghorn *previously general sales manager, has been made general Commercial Manager of Compoflex Ltd with direct responsibility for home and export sales.* **Mr J. Pickthall** *becomes home sales manager and is assisted by* **Mr C. V. Hadley** *in charge of the liquids handling side; by* **Mr H. J. Bergin** *on non-liquids.*

Mr B. W. Kerrigan *has been appointed secretary of the Institution of Mining and Metallurgy.*

Mr G. Ensor *BSc, AMIEE, a director of Fielden Electronics Ltd becomes general manager and* **Mr Victor Thomas,** *general sales manager.*

Mr E. W. Bussey *CBE will relinquish his appointment as chairman of the Employers Side of the Joint Negotiating Committee for the Electricity Supply Industry on December 31. Mr Bussey began his career in the supply industry in 1909.*

Keith Blackman Ltd recently announced three new directors: **Mr C. J. Atkins,** *sales director;* **Mr G. W. Goodge,** *contracts director;* **Mr S. Hudson,** *director and London works manager.* **Mr A. H. Woodley** *was made sales manager.*

Mr F. W. Martin *has given up his position as joint managing director of Tube Products Ltd, Oldbury, to become deputy chairman. He is succeeded by* **Mr E. D. E. Andrewes** *who relinquishes the joint managing directorship of Accles and Pollock Ltd but who retains his directorship.* **Sir Archibald Gill** *BSc (Eng) MIEE, has joined British Telecommunications Research Ltd as director and general manager.*

Thermal Power from Nuclear Reactors *by A. S. Thompson and O. E. Rodgers.* 6 in. x 9·25 in. pp. 229. New York: John Wiley, London 1956: Chapman & Hall, Price 58s

The first thing to be said about this book is that its title is most misleading. The implication in the title is that it mainly deals with the problems of the removal of heat from nuclear reactors. In fact, this aspect is not dealt with until p. 186 and then only occupies 20 pages.

The book, in fact, deals mainly with the subjects usually known as reactor physics or reactor theory. It opens with a discussion of the facts of nuclear physics necessary for the understanding of how and why a reactor works and then goes on to discuss the simple equations which govern the neutron behaviour in a reactor and the quantities which determine the critical size. (It is unfortunate that the authors make the common error of stating that the neutron flux is the number of neutrons crossing unit area in unit time). This latter chapter, however, contains a useful treatment of the numerical solution of the reactor equations.

The important topic of reactor kinetics is next discussed with particular reference to non-linear kinetics—again with emphasis on numerical methods. The shielding problem is then dealt with quite briefly and this is followed by a summary of the properties of materials used in reactors.

Thermal stress is dealt with at some length as the first part of what might be described as the engineering part of the book and this is followed by a chapter on power extraction from reactors and finally a chapter on thermal power cycles.

The authors have tried hard to produce a simple treatment of their subject and have not always succeeded. Also it seems a pity in a book primarily intended for engineers that there are not more graphs and tables of data.

James F. Hill

Power Production *by Hans Thirring.* 6in. × 8½in. 399pp. London 1956: Geo G. Harrap. 25s net

Humanity's three great tasks, maintains Professor Thirring, are: food production, power production and education and although his book is concerned with the second, the first is, in his opinion, 'the most urgent', the third 'the most noble'.

By education, however, he means not merely the abolition of illiteracy but the enlightenment of the so-called 'educated' and reigning classes. Only in societies led by men educated in this broader sense, will global welfare projects become possible. So although the book is devoted to power production it is also an attempt to tackle his third task. The difficulty in all this is that the grasping of even a simple scientific concept such as power or work is almost beyond the reach of anyone not possessed of a basic knowledge of natural philosophy. This cannot be obtained just by sitting down with a good book: one has to really do one's sums before the significance of the writing begins to emerge. Unfortunately only a certain proportion of otherwise intellectually gifted people have the talent or inclination for this. Nothing daunted, Professor Thirring takes on the monumental task of making the subject of global energy production intelligible to the general reader and if it is probably well over the head of the majority, the scientifically inclined will undoubtedly find it stimulating. The general plan of the book is to describe in some detail the means of producing energy and then to examine sources of energy which can be used in these machines. No possible source of energy from coal to biological and solar methods seem to have been left unexplored and he abundantly succeeds in conveying an impression of fantastic waste.

Prof. Thirring is particularly interesting on water power and he includes a description of the vast Brahmaputra project which he recently put forward at the Fifth World Power Conference in Vienna. In a nutshell, this, at the lowest estimate, would produce in a single plant nearly three times the present electricity output from all sources in the U.K. On nuclear energy he provides a highly competent popular survey and includes an illuminating chapter on thermonuclear reactions.

Although written in excellent English (it is not a translation) there is a certain confusion about units and at least one metric enthusiast found himself longing for the replacement of our antiquated system. The advent of nuclear power could have provided the opportunity to change, but with the Americans solid for the B.t.u. the moment seems to have passed.

W.D.

Atoms in Industry I and II London 1956: Political and Economic Planning, 16 Queen Anne's Gate, S.W.1, Price 2s 6d each

These two slim pamphlets form issues no. 388 and 389 volume XXII of PEP'S journal *Planning* and are intended to provide an overall picture, not of the theory of atomic energy, but how it is being organised in this country. The first volume is devoted to the organisation of United Kingdom Atomic Energy Authority and to the British White Paper Plan for nuclear power generation.

The second volume continues with a discussion of the siting of power stations and the problems connected with their insurance. It then goes on to discuss isotopes and concludes with a review of the present position on international cooperation.

THE G.E.C. SIMON-CARVES Atomic Energy Group have published a brochure which details the position the group is establishing in the field of atomic energy.

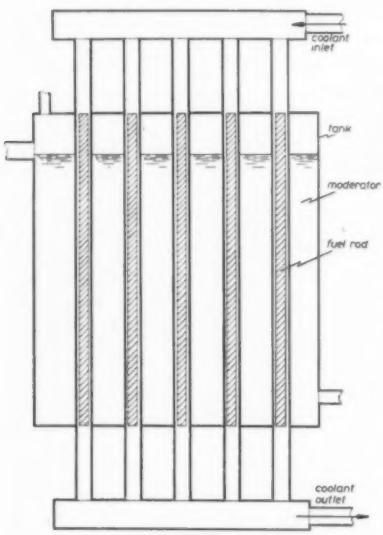
BAIRD AND TATLOCK (LONDON) LTD, Freshwater Road, Chadwell Heath, Essex, recently issued their Bulletin and Laboratory News, Series 2, No. 25. This includes descriptions of several items of new equipment including an interesting small Van de Graaft generator for demonstration use with a maximum potential of 450,000 volts.

PATENTS

These abstracts are made from British Patent Specifications with the permission of the Controller of Her Majesty's Stationery Office. Complete specifications may be obtained from the Patent Office (Sales Branch), 25 Southampton St, London, WC2, 3s. a copy (inc postage, inland & abroad)

753,130 ***Improvements in atomic-energy producing devices*** *United Kingdom Atomic Energy Authority (Inventors: S. G. Bauer and R. E. Newell) July 18, 1956*

Dating from 1945 the invention relates to a type of liquid-cooled heterogeneous reactor in which the liquid coolant and moderator may be controlled separately. One application of the invention is shown in the diagram. The core is contained in a right cylindrical tank. The fuel rods are held in vertical holes which connect



Liquid coolant and moderator are kept separate in this heterogeneous reactor

to headers above and below the tank which is filled with a moderating fluid such as heavy water. The cooling fluid may be light or heavy water and the flow can be adjusted to give optimum operation without affecting the moderator which is cooled in a separate heat exchanger. A modification of the invention is to have tubular fuel elements, thus dispensing with the tubes enclosing the fuel rods. Alteration of the moderator level in the tank may also be used to control reactivity.

754,651 ***Improvements in or relating to methods of separating plutonium*** *Frank Morgan, August 8, 1956*

First filed in 1946, the invention describes a method for separating plutonium, uranium and mixed fission products including zirconium and niobium from irradiated fuel elements. The rods are first dissolved in nitric acid with the addition of nitrates of zirconium and niobium as carrier compounds. An aqueous solution of a soluble phosphate is added which causes precipitation of insoluble phosphates of plutonium, zirconium, bismuth and niobium. These are treated with oxalic acid whereby the compounds of zirconium and niobium are rendered soluble and an insoluble residue of bismuth and plutonium oxalates is formed. The final step is the separation of the plutonium from the bismuth which can be done in several ways.

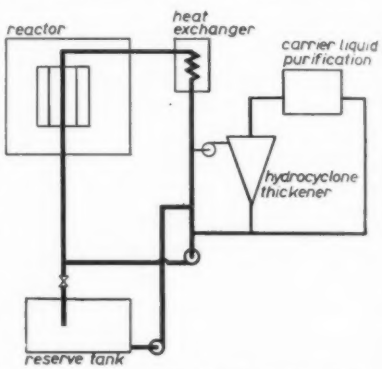
750,815 ***Improvements in or relating to methods of producing radioactive preparations from metals or metal alloys made radioactive by nuclear reactor*** *N.V. Philips' Gloeilampenfabrieken, Eindhoven, Netherlands*

According to the electromotive force series of elements a metal may be used to replace any other metal below it in the series from its salts, it being possible for the metal liberated to deposit on the expelling metal.

The patent can best be illustrated by one of the examples given:—About 2 gm of silver irradiated with deuterons in a synchrocyclotron were dissolved in nitric acid. The solution was evaporated to a small volume to remove excess of nitric acid, then diluted with water and subsequently made substantially alkaline with the use of ammonia. 20 gm of de-greased tin filings were added to the resultant liquid, and the solution boiled for 20 minutes. The tin on which the silver ions had deposited was removed by filtration, 10 mgm of iron chloride being added to the filtrate containing the isotope Cd-109. Subsequently, the solution was made alkaline and boiled whilst adding some drops of hydrogen peroxide. The deposit consisting of iron hydroxide and cadmium hydroxide was dissolved in a small amount of hydrochloric acid, whereafter the solution was given a pH value of about 3 with ammonia and ammonium acetate. Subsequently, the solution was shaken out with a mixture of benzoyl acetone and toluene, the iron chloride of the aqueous layer passing into the organic layer. The aqueous layer contained substantially all the radio-active cadmium produced by the bombardment, but was free from silver and iron ions.

753,399 ***Process of Nuclear Fission*** *Stichting voor Fundamenteel Onderzoek der Materie, Utrecht, Netherlands, July 26, 1956*

In the fission process, the growth of powerfully neutron-absorbing poisons reduces the reactivity and so they have to be removed periodically. This is a complicated process whether the fuel is in the form of solid rods or a solution. The present invention claims to obviate this by using a stable suspension of solid fuel particles in a carrier liquid. These



Layout of a slurry reactor shows continuous fuel processing

particles should have a diameter not more than 15 microns.

The separation of the suspension from the carrier liquid may be done by a hydrocyclone thickener, the overflow fraction, consisting substantially of carrier liquid, being then purified and returned to join the apex function to form a new fuel suspension.

751,429 ***Nuclear Reactor*** *Stichting voor Fundamenteel Onderzoek der Materie, Utrecht, Netherlands, June 27, 1956*

In a non-boiling reactor an upper limit to the coolant temperature is set by the critical temperature of the liquid. Even this means very high pressures (300°C, 1200 lb/in² for H_2O and D_2O). The inventors believe that pipes inside the reactor, to withstand this pressure would have to be impossibly thick from a nuclear absorption point of view and it is proposed to include the entire reactor, including at least a substantial part of the reflector, within a pressure vessel. It is claimed that this shell will also serve to reduce the amount of gamma shielding required.

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BOARD OF TRADE

XIMEX

Elliott-Giannini agreement

Under a recently-announced agreement with Giannini Ltd, of 45, Gresham Street, London, EC2 (the British affiliate of the American company G. M. Giannini and Co Inc of Pasadena, California), Elliott Brothers (London) Limited are to manufacture and market Giannini shaft-rotation digitisers.

These are a range of specially designed commutators which enable shaft positions to be converted without ambiguity to electrical signals. They may be used for the conversion of physical variables such as pressure, motion, temperature, flow, etc., into a form suitable for entry into a digital computer, and/or for making permanent records in digital form of the information concerned. Typical commutators have 1,000 discrete steps for 360° rotation (or less in some designs).

Special "translators" are available which will store very short-duration output signals from the commutators for sufficient time to operate comparatively slow recording or printing equipment (e.g. electric typewriters, card punches or tape punches). This makes it possible to record very rapidly changing data, error-free operation being obtainable up to rotation speeds of at least 120 rev/min.

The commutators are suitable for attachment to most standard types of self-balancing potentiometer recorder, and have already been successfully used with the well-known Bristol Dynamaster, manufactured in England by Bristol's Instrument Company, a subsidiary of Elliott Brothers.

EIL choose Bradford

Expanding sales in the North of England, coupled with the increasing number of industrial installations, have led Electronic Instruments Limited to open a new service centre in Bradford at 8 Duke Street. This centre, under the personal direction of Mr A. C. Stewart, has been equipped with instruments and spares to provide full repair facilities and to act as a showroom and demonstration centre for the firm's products.

The city of Bradford has been selected because of its situation, which gives excellent coverage for the main industrial areas in the north of England.

One of the Company's principal activities is concerned with the manufacture of industrial pH equipment. The complex nature of some of these installations and the high intrinsic value of the processes being controlled, has prompted the Company to introduce a fleet of pH Mobile Service Units. This pH service, which is claimed to be unique, ensures that every E.I.L. customer is regularly visited by a skilled engineer to ensure that the plant is working at its best efficiency. One of the Mobile Service vans is stationed at the new Bradford centre and tours the North and North Midland counties.

Soviet Minister at Fielden

Mr M. E. Rokovskiy, Deputy Minister of Automation for the USSR, recently made a tour of inspection at Fielden Electronics Ltd, of Wythenshawe, Manchester. Although originally he planned to spend only one hour, he passed the whole day there, cancelling a scheduled visit to a power station to do so.

During the visit, the Deputy Minister appeared to be very well informed on industrial instrumentation, and seemed extremely impressed by what he saw in the works. He was shown round by Mr J. E Fielden, founder of the firm and Governing Director, and afterwards he invited some Fielden personnel to visit Moscow. Mr V. Thomas, Fielden's Sales Manager, later attended a farewell party for Mr Rokovskiy at the Russian Embassy in London.

Since Mr Rokovskiy's visit, several enquiries have been received from countries beyond the Iron Curtain.

GEC laboratories renamed

Three laboratories of The General Electric Company Ltd. at Stanmore (Middlesex), Brown's Lane (Coventry) and Salisbury (South Australia) have been renamed under a group title of *Applied Electronics.*

Names and addresses of these establishments are now as follows:—

The General Electric Company Limited,
Applied Electronics Laboratories,
The Grove,
Stanmore, Middlesex.

The General Electric Company Limited,
Applied Electronics Laboratories,
Brown's Lane,
Allesley, Coventry.

The General Electric Co Ltd of England
Applied Electronics Laboratories,
P.O. Box No. 127,
Salisbury,
South Australia,
Australia.

Lab ware price peg

It is hoped that prices of laboratory apparatus will be held stationary for a period in accordance with Government policy as a result of a resolution carried by a general meeting of the British Laboratory Ware Association held last month in London. The resolution pledges members to maintain for six months prices existing at September 1 for both home and overseas sales. It was also agreed that non-members should be asked to cooperate with the Association in this matter.

Babcock Developments

Under Chief Engineer W. F. C. Schaap, Babcock and Wilcox Ltd. set up a new Atomic Energy Department on October 2. Chosen as manager of this important new development was erstwhile Renfrew research chief T. B. Webb, with W. R. Wootton as assistant manager (see 'names in the news').

The new department will be responsible for development, proposition and contract engineering in the atomic energy field and will collaborate closely with the existing Babcock sales, engineering, commercial and manufacturing departments. The company say they attach the greatest significance to this new venture which is destined to grow rapidly in size and responsibility in conformity with the sharply rising curve of atomic development in Great Britain and throughout the world.

Dunlop start irradiation

Said to be the first of its kind in the British rubber industry, Dunlop recently opened a new laboratory at their Birmingham research centre for the study of the irradiation of rubber and plastics. The laboratory is equipped at present with a 100 curie cobalt-60 source but it is planned to supplement this with a 1000 curie source when it becomes available. According to director of research, E. A. Murphy, irratiation can be used for vulcanizing materials which are intractable by normal processes and can also produce new types of synthetic polymers. The laboratory uses comprehensive shielding arrangements and elaborate safety devices.

Kent dividend maintained

A slight drop in group net profits from £167,800 to £161,423 for the year ended March 24 was a feature of George Kent Ltd's operations. A final dividend of 12 per cent to make 15 per cent for the year on the £720,000 Ordinary capital was recommended and is the same as last year on a smaller capital. A one-for-two rights issue was made last September. George Kent are among the foremost suppliers of industrial measuring instruments to the AEA establishments.

World's reactors now 75

More than 75 nuclear reactors have so far been constructed in the world according to a survey undertaken by the German monthly *Die Atomwirtschaft.*

A special July/August 'reactor issue' of the magazine contains 15 pages of tabular data for 63 types of reactor, some of which, like the Hareford and Savannah reactors, are duplicated. A critical appraisal of the various reactor types is given by Dr R. Schulten. Other contributions include a discussion of problems of nuclear power programmes by Prof Karl Wirtz and a commentary on the new German nuclear energy bill by Dr M. Scheidwimmer of the German Ministry for Atomic Affairs.

British agents for *Die Atomwirtschaft* are: Rowse Muir Publications Ltd, 3 Percy Street, London, W.1.

Plessey set up US company

The Plessey Company of Ilford has formed an American Corporation, Plessey Incorporated, to handle its interests in the United States. The firm have a number of agreements and associations with American companies and the new corporation will facilitate relations with them. Meanwhile, Plessey's Chicago office has been closed and now all business is being handled by Plessey Incorporated at 41 East 42nd Street, New York City, NY. President is Mr W. J. Sinsheimer.

Plessey have been very active in nuclear energy in this country and are responsible for the burst cartridge detection installation at Calder Hall.

INSTITUTIONS

Magnetic Resonance

A symposium is being arranged by the Liverpool and North Wales Branch of the Institute of Physics at the University College of North Wales, Bangor, on September 26 and 27.

Lectures will be given by Dr B. Bleaney (Clarendon, Oxford) on *Free Atom Resonance*, Dr J. G. Powles (QMC, London) on *Spin Echo Techniques*, Dr R. E. Richards (Oxford) on *Magnets*, and Professor E. R. Andrew (UCNW, Bangor) on *Nuclear Magnetic Resonance work and other research at Bangor.*

Further particulars may be obtained from Professor E. R. Andrew, Physics Department, University College of North Wales, Bangor, Caernarvonshire. Accommodation will be available for a limited number.

New instruments at Stockholm

The Instruments and Measurements Conference to be held in Stockholm from September 17-19 will include a special section on nuclear instruments This will commence at 10 o'clock on September 17 with an address by Dr Denis Taylor (Instrumentation Editor of NUCLEAR POWER) on *Design trends in radiation monitoring instruments for uranium prospecting and other purposes.* He will be followed by R. L. Butenhoff, instrument chief of the USAEC, on *Nuclear Instruments in the USA.* Other papers in this section will be: Dr. K. E. Larsson, A.B. Atomenergi, *A xenon gas scintillation fission counter;* I. Braun, A.B. Atomenergi, *A new alpha probe for personnel monitoring;* K. Johansson, A.B. Atomenergi, *A logarithmic gamma monitor;* J. S. Lindhe, A.B. Atomenergi, *A thin window proportional flow counter;* A. B. Gillespie, Harwell, *Recent development in electronic equipment for nuclear energy research;* Dr E. Franklin, Harwell, *Scaling system using magnetic memory;* Dr A. G. Stebler, Landis und Gyr A.G., *A simple radiation measuring instrument and its applications;* E. Berne, Göteborg, *Scintillation scanning as a tool for medical diagnostic work;* K. Kandiah, Harwell, *The design of multichannel analysers in nuclear physics;* Dr J. Kohl, Tracerlab Inc, *Radiation spectrometers and their applications in industrial tracer experiments;* Dr R. V. Gasstrom, Holland, *A new type of pulse-height analyser utilizing a cathode-ray tube with a photo-transistor sorting element;* K. Ljunggren, Stockholm, *A scintillation detector designed for industrial investigations with some applications;* J. Bjorkman, A.B. Atomenergi, *Synchronizing neutron chopper and time analyzer;* Dr O. Beer, Germany, *Materials for protection against radioactivity;* J. L. Putman, Harwell, *Developments in the use of radioisotopes in industrial research and process control;* E Rotkirch, Helsinki, *Use of radioisotopes for process investigations in Finland, Mixing pattern in cement factory raw meal basin;* L. G. Erwall, Stockholm, *Recent industrial applications of radioisotopes in Sweden;* Dr U. S. Landergren, SKF, Sweden, *A radioactivity method for measuring wear in ball bearings;* Ingrid Fineman, Stockholm, *Scintillation spectrometry applied to activation analysis with special regard to copper and manganese;* U. A. Luoto, Helsinki, *A method of half life correction during industrial investigations with short-life isotopes.*

BNEC Programme

The September meeting is sponsored by the Institution of Civil Engineers and will be held at the Institution—the paper to be read will be *The problem of liquid and gaseous effluent disposal at Windscale* by F. R. Farmer. The October meeting will be at the Institution of Electrical Engineers, and will be *Conduction and induction pumps for liquid metals* by L. R. Blake.

'H-power certain'—Thomson

Thermonuclear reactions might make it possible to obtain electricity direct, without the intervention of a heat engine, according to Sir George Paget Thomson FRS addressing the 118th Annual Meeting of the British Association for the Advancement of Science in Sheffield on August 30. Referring to the thermonuclear process, Sir George declared 'I have no doubt that in the not very distant future it will be tamed for peaceful purposes. Whether it will greatly improve on uranium and thorium remains to be seen. It will depend on how complex the devices have to be to release it. In the long run I think it may win, as I believe there is much more possibility of deriving electrical energy directly from a nuclear reaction in the case of deuterium than in the case of uranium, and this would save the inefficiency of the heat engine that now interposes itself. It is also possible that a combination of the two might prove economic. The deuterium reaction produces neutrons—these might be used to turn uranium into plutonium, or thorium 233, thus producing very valuable material which can be used to enrich normal uranium'.

Referring to the limitations of nuclear power, Sir George said the chief one was the necessary shielding. For this reason he saw not the slightest hope for the nuclear motor car, and he had grave doubts about the nuclear aeroplane—for the Atlantic crossing he did not believe that the saving in fuel weight would compensate for the weight of the shield and the increased complexity of the machinery, at least in an aeroplane of anything like the present size.

The application of atomic power to make Antarctica habitable was mentioned by Sir Raymond Priestley in his Presidential Address *Twentieth Century Man Against Antarctica.* Sir Raymond said that now nuclear icebreakers could be built, there was no reason why atomic-powered settlements should not be set up on the mainland. But this would only be practicable if a worth-while economic objective were discovered. This was not in sight yet but he was sure there must be great and valuable mineral deposits to be found and there was also the possibility of using Antarctica as a gigantic world food store.

RESEARCH REPORTS

United Kingdom

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Atomic Energy Research Estabt.

The volumetric determination of uranium in aluminium-uranium alloys. A. Bacon, G. W. C. Milner. (Mar 21, 1956. 21 pp) 3s 3d. AERE-C/R 1813*

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Oxidation of potassium. Report of progress to 31/1/56. P. B. Longton. (May 14, 1956. 12 pp) IGR-TN/C 336

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The properties of zirconium and its possibilities for thermal reactors. Harold B. Fairchild. Oak Ridge National Lab, Tenn. Jan 1949. Decl. with deletions Jan 1956. Contract W-7405-eng-26. 106 pp. Order from LC. Mi $5·70, ph $16·80. AECD-3891

Textures in rolled uranium rod. W. P. Chernock, L. W. Kates. Sylvania Electric Products, Inc, Bayside, NY. Apr 1952. Decl. Jan 1956. Contract AT-30-1-gen-366. 21 pp. Order from LC. Mi $2·70, ph $4·80. AECD-4001

Development of zirconium alloys, Part I. A. D. Schwope, L. L. Marsh, W. Chubb. Battelle Memorial Inst, Columbus, Ohio, Aug 1951. Decl. Nov 1955. Contract W-7405-eng-92. 22 pp. Orders from OTS. 25c. BMI-79

Development of zirconium alloys, Part II. A. D. Schwope and W. Chubb. Battelle Memorial Inst, Columbus, Ohio. Jan 1952. Decl. Nov 1955. 25 pp. Order from OTS. 20c. BMI-718

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Temperature coefficient of the LMFR. J. Fleck. Brookhaven National Lab, Upton, NY. Jul 1954. Decl. Nov 1955. Contract AT-30-2-gen-16. 3 pp. Order from OTS. 10c. BNL-2390

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High density concrete shielding. Supplement title: Heat testing of high density concrete. C. R. Binner, C. B. Wilkie, Philip Miller. H. K. Ferguson Co, Inc, New York, NY. Feb 1949. Decl. Sep 1955. Contract AT-30-2-gen-16. 49 pp. Order from OTS. 35c. HKF-1 and Suppl.

Proportional counters for use with neutron velocity selector. E. B. Fehr, E. C. Palmer, W. J. McRoberts, Knolls Atomic Power Lab, Schenectady, NY. Dec 1955. Contract W-31-109-eng-52. 19 pp. Order from OTS. 20c. KAPL-1110

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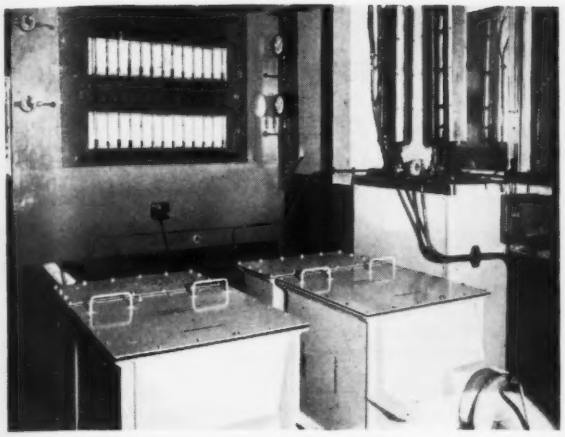

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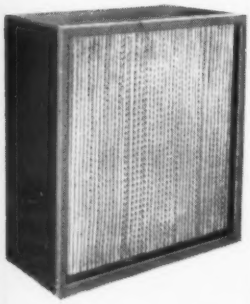

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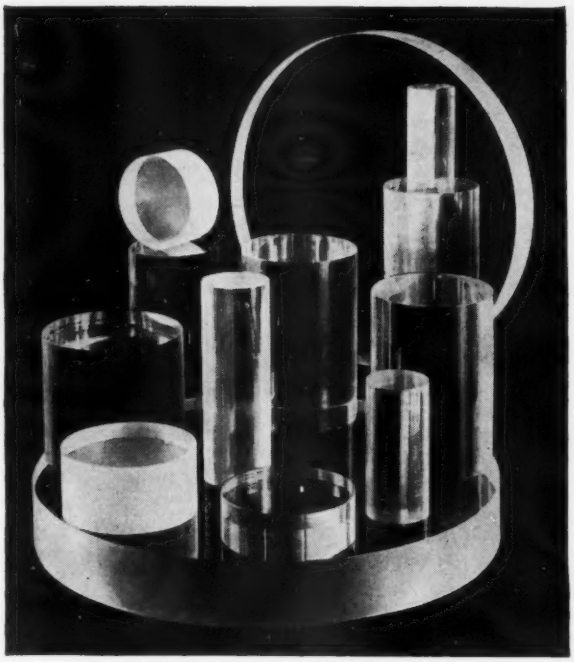

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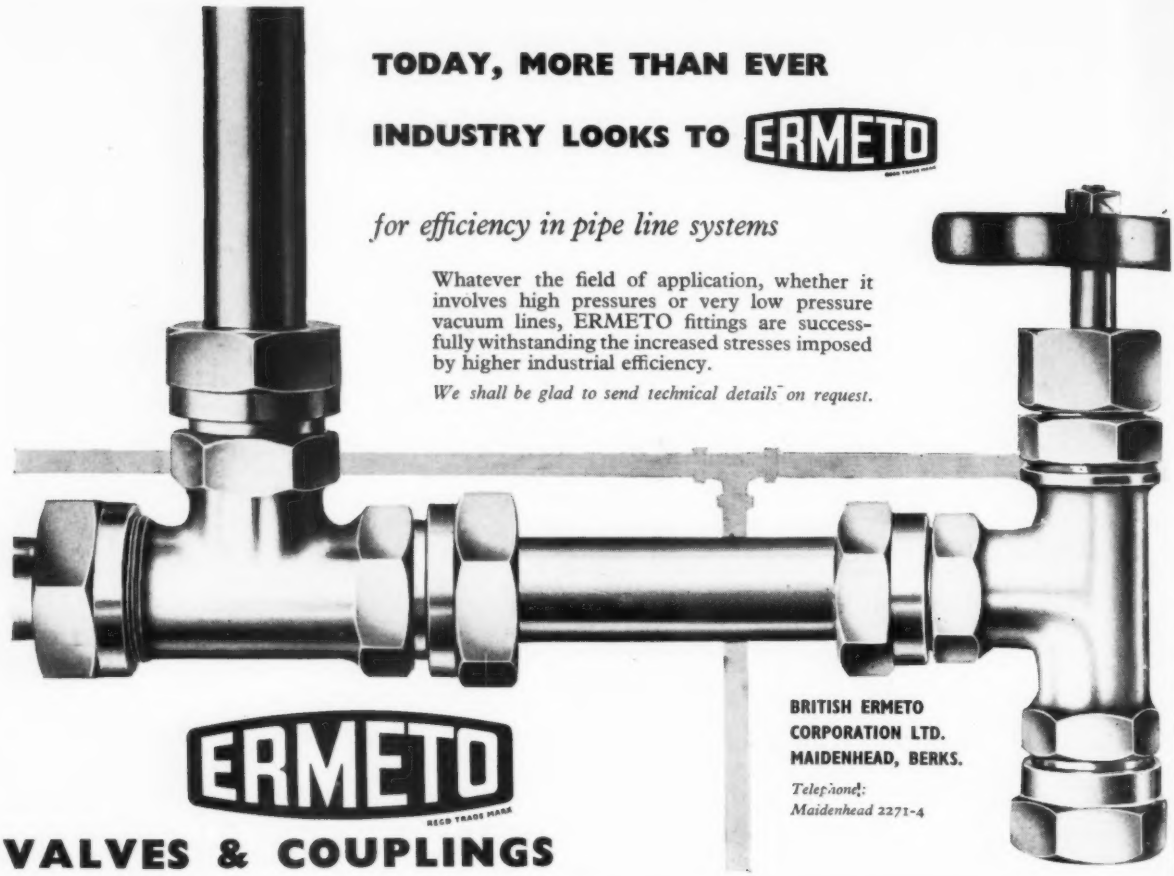

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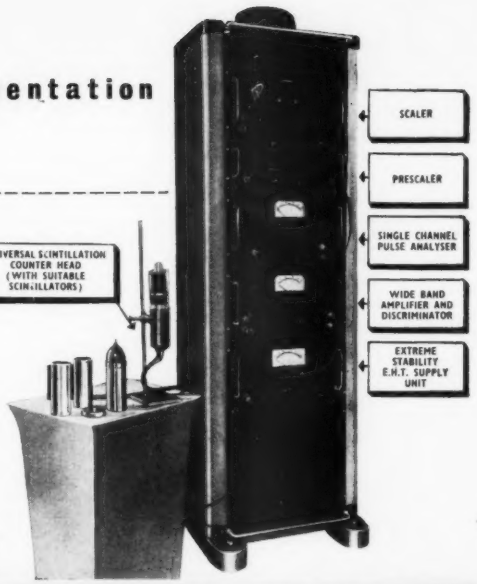

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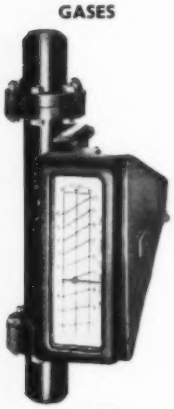

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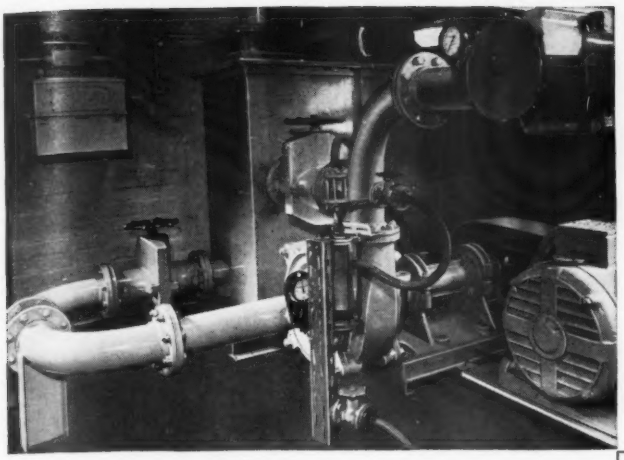

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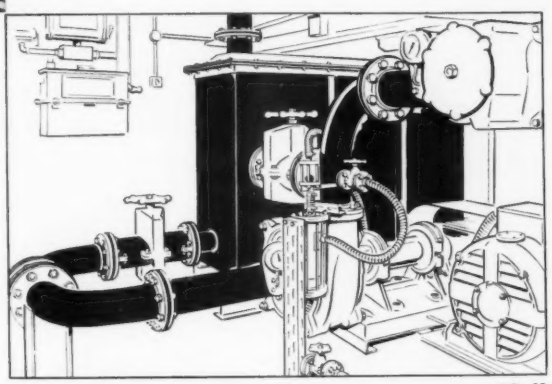

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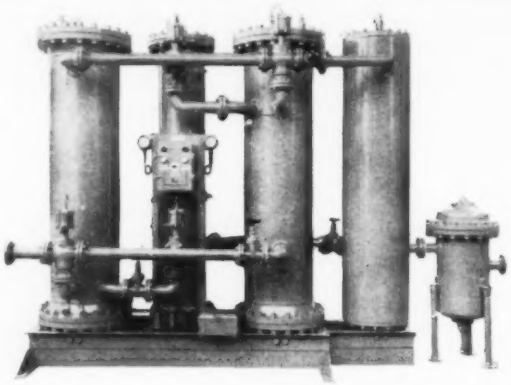

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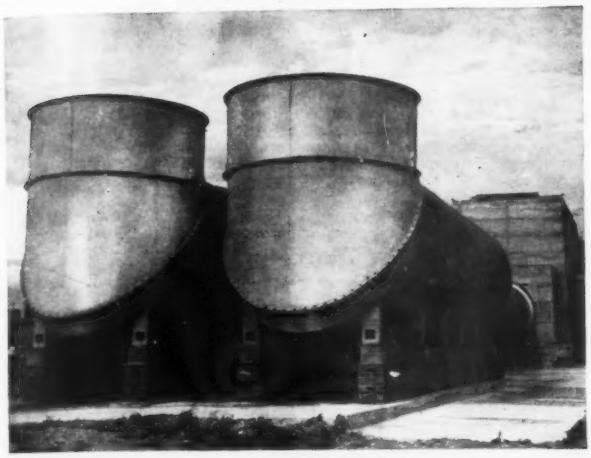

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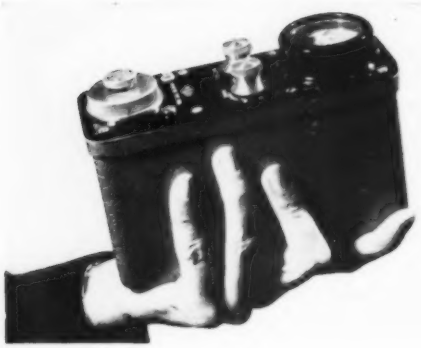

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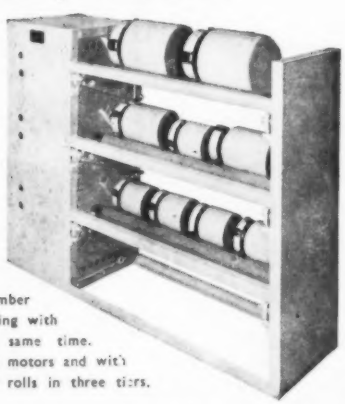

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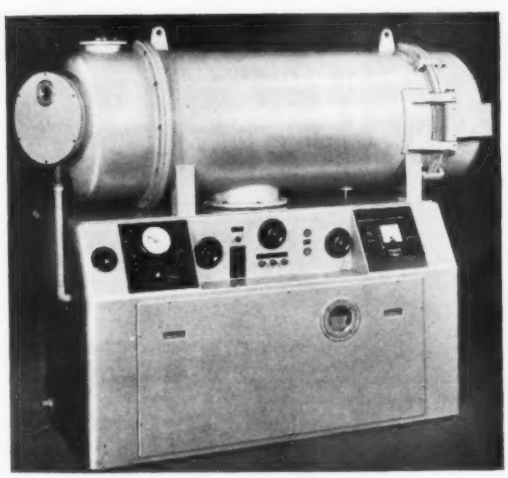

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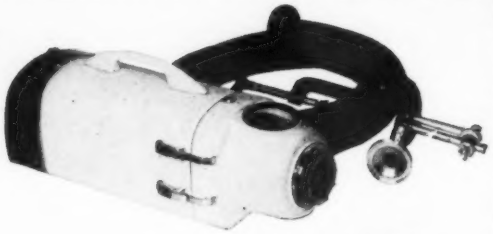

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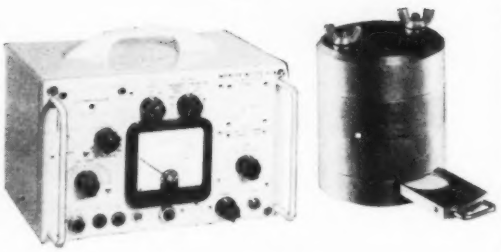

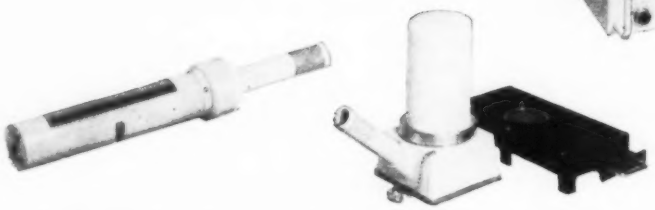

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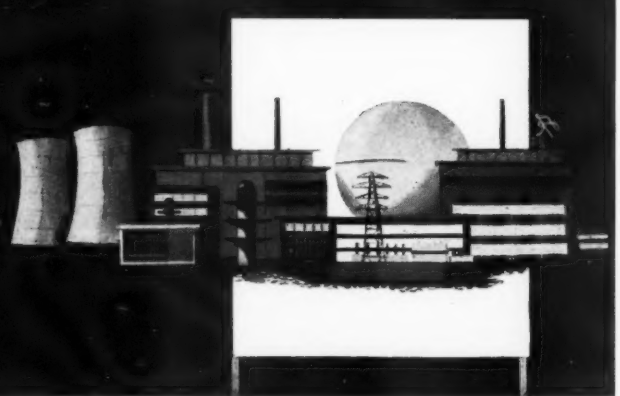

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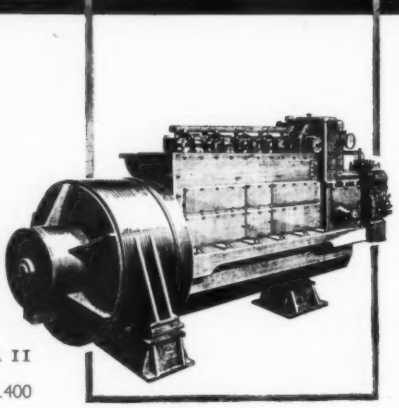

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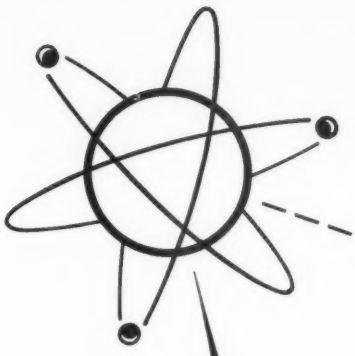

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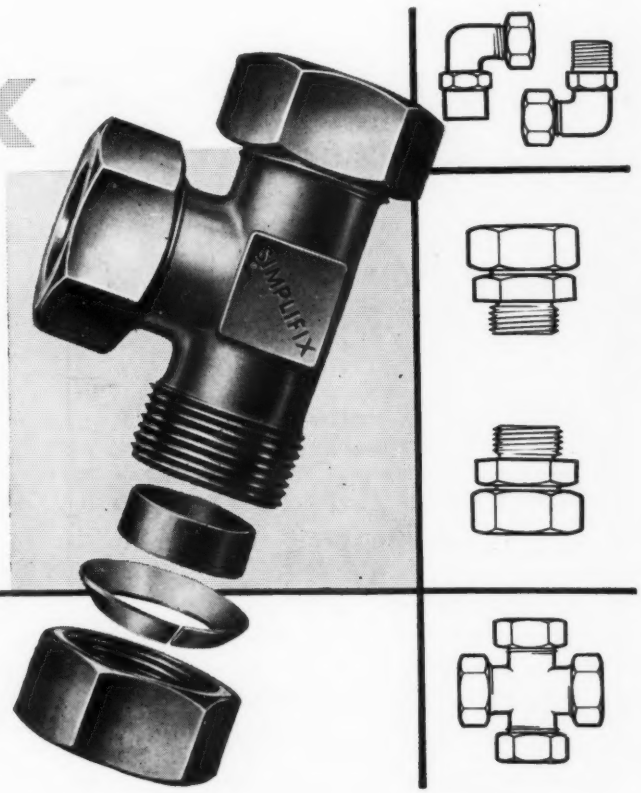

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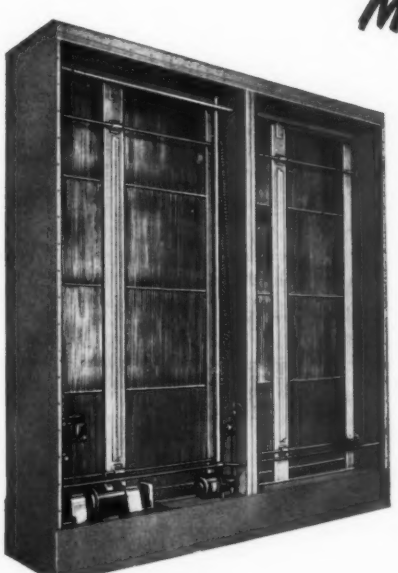

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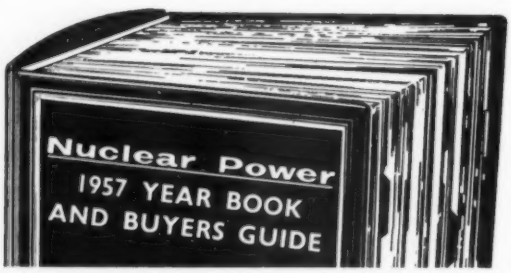

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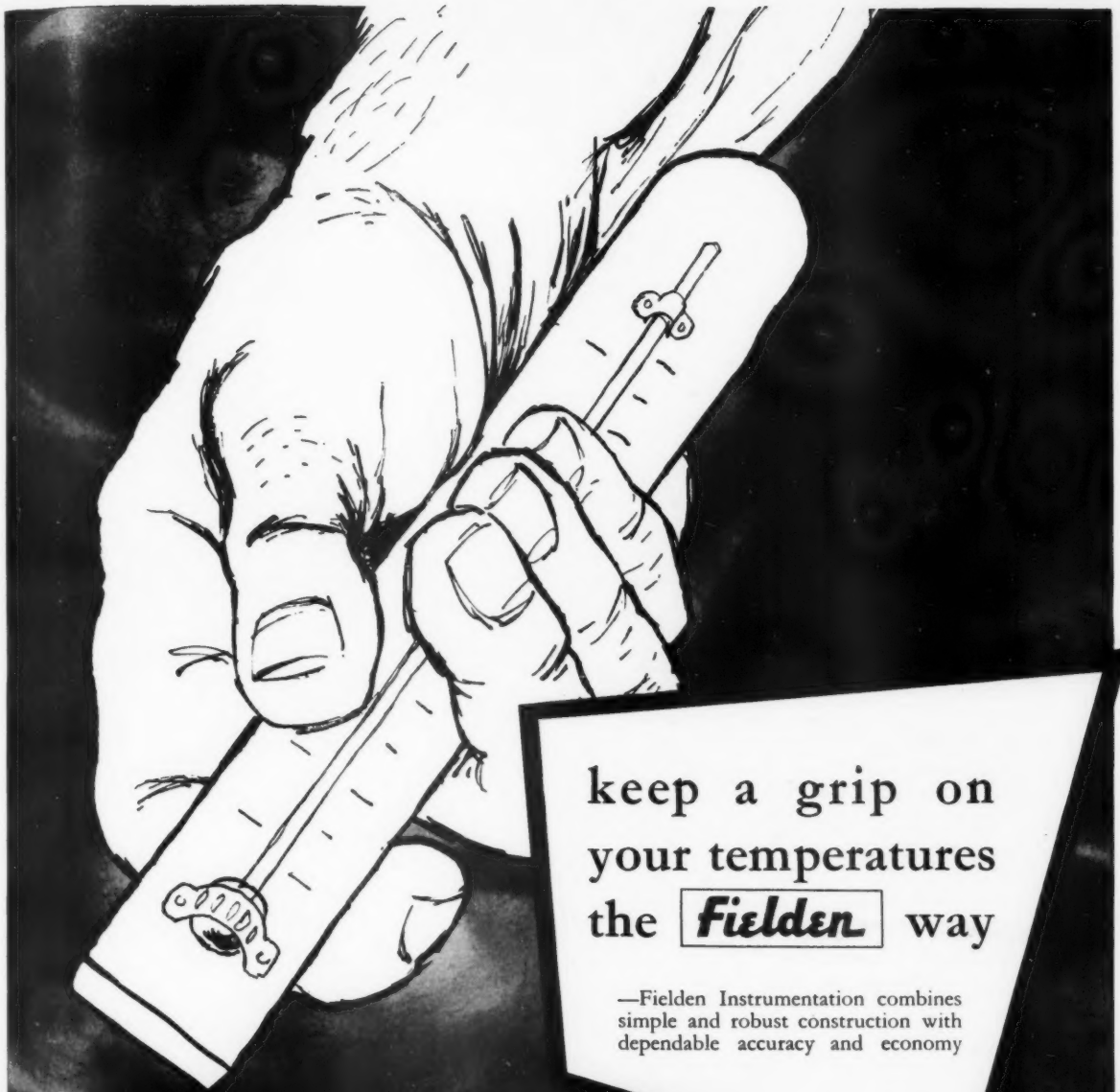

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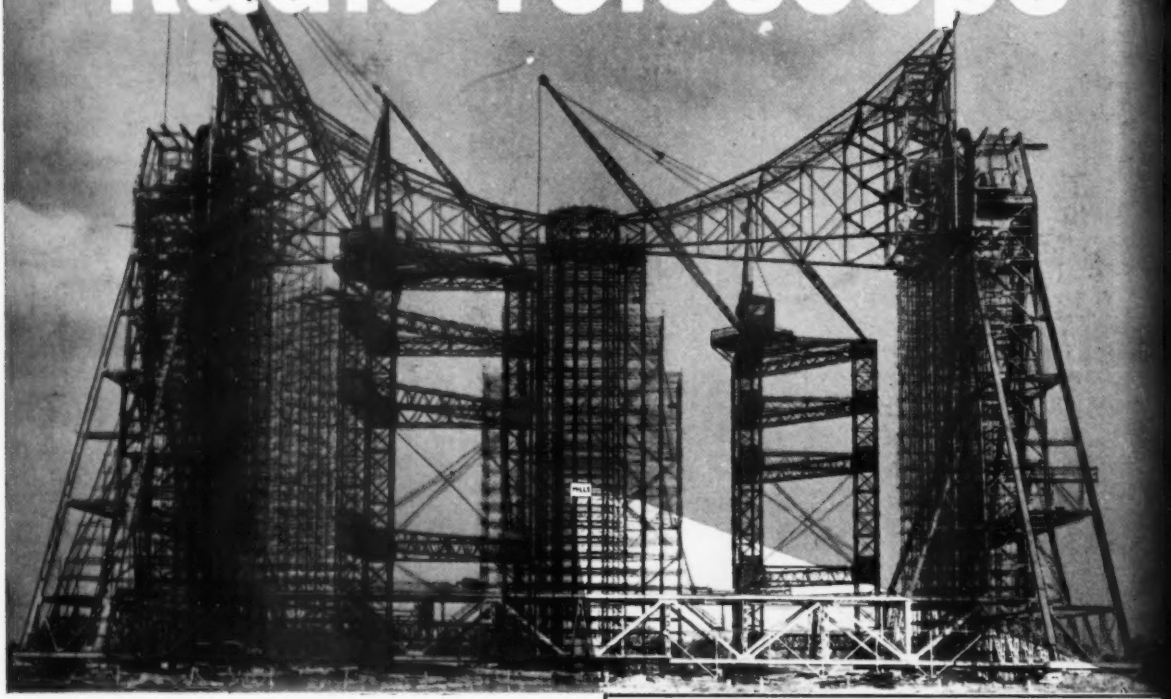

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